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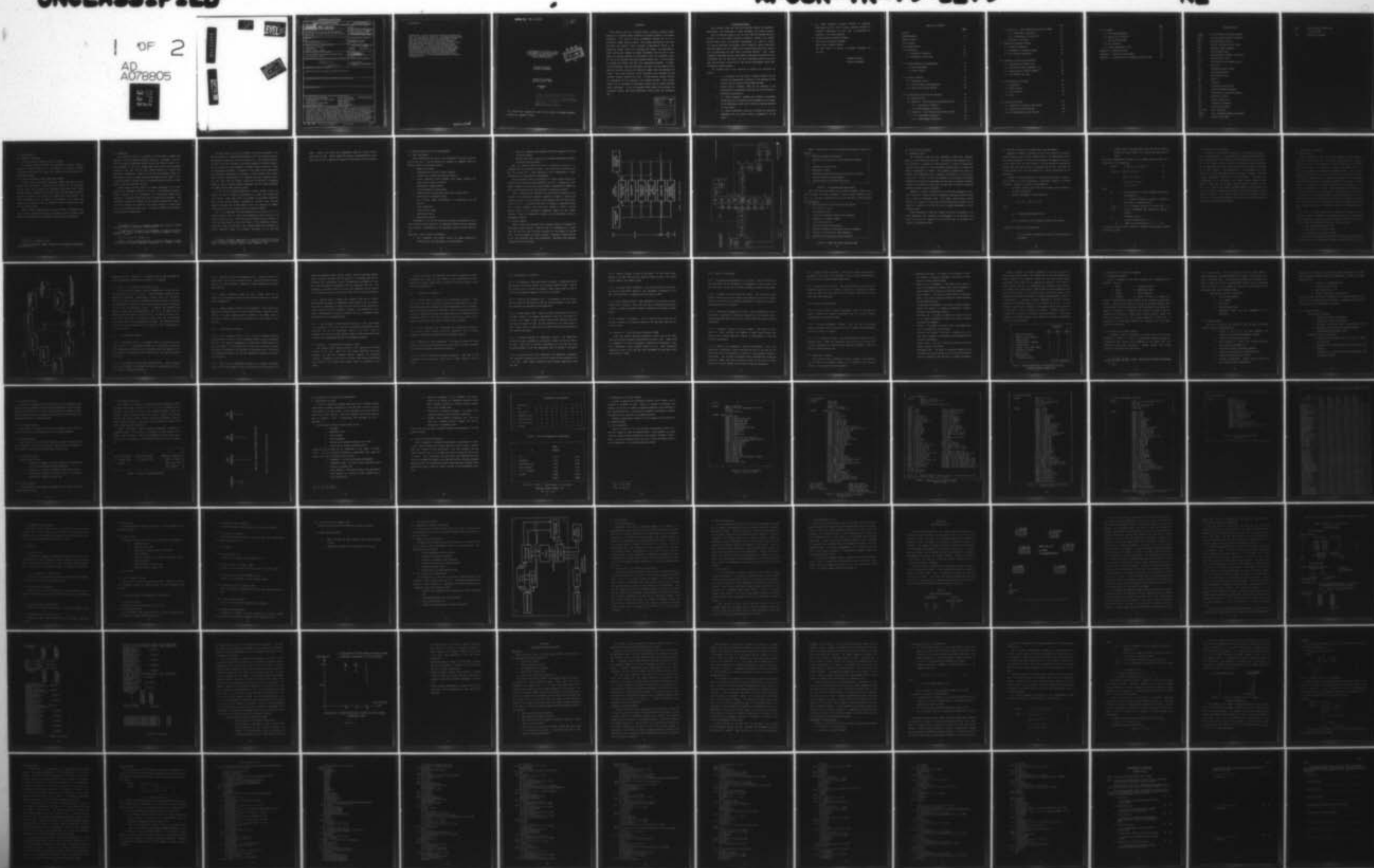

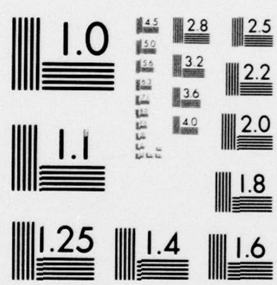

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER 19 — 18 AFOSR TR- 79-1279
2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER — 9
4. TITLE (and Subtitle) — 6 Preliminary Activities in the Development of MX Maintenance Control Through Use of a Design Morphology.
5. TYPE OF REPORT & PERIOD COVERED — Interim Technical Report. 1 Oct 78 — 30 Sept 79
6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) — 10 Benjamin Ostrofsky (et. al.)
8. CONTRACT OR GRANT NUMBER(s) — 15 F49620-77-C-0116
9. PERFORMING ORGANIZATION NAME AND ADDRESS — University of Houston, 4800 Calhoun, Houston, Texas 77004
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS — 61102F, 2313A4 — 12 96
11. CONTROLLING OFFICE NAME AND ADDRESS — Air Force Office of Scientific Research (NL), Bolling AFB, DC 20032
12. REPORT DATE — 11 Sep ~~tember~~ 1979
13. NUMBER OF PAGES — 90
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) — 16 2313 — 17 A4
15. SECURITY CLASS. (of this report) — Unclassified
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Design Engineering Methods
Planning Methods for Large Systems
System Design
Human Resource Requirements
Human Resource Data
Life Cycle Costing
Design Trade Studies
System Analysis
Human Factors
Human Engineering
Design Morphology

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This study is part of a continuing effort to improve aerospace system design and to consider human resources and logistics factors properly in the design procedures. The study is being accomplished through the use of a structured, design decision process. The problem approached is the Fault Detection and Dispatch (FDD) activities of Maintenance Control in the Operations Control Center of a prototype MX system. By approaching a highly unstructured problem the design morphology used was able to show clearly the required elements of the problem in their true perspective. Hence the role of the operators and other personnel

become clear. In this research the problem was defined and basic FDD requirements identified. A computerized maintenance model was developed and tested, and the elements of the protective structure location were defined for impact upon the emerging FDD system. Three basic scenarios for MX maintenance were identified and 180 candidate systems developed for FDD. A multi-attribute criterion function was approached for the evaluation of the candidate systems. This criterion function will be developed in subsequent research and the optimal candidate chosen analytically. A list of desirable trade studies was developed and subsequent activity will clarify Maintenance Control tasks and information flow.

AFOSR-TR- 79-1279

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PRELIMINARY ACTIVITIES IN THE DEVELOPMENT OF MX MAINTENANCE CONTROL THROUGH USE OF A DESIGN MORPHOLOGY

Benjamin Ostrofsky
Principal Investigator

University of Houston
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September
1979

This research was supported by the Air Force Office of Scientific Research

Contract No. F49620-77-C-0116

ABSTRACT

This study is part of a continuing effort to improve aerospace system design and to consider human resources and logistics properly in the design procedures. The study is being accomplished through the use of a structured, design decision process. The problem approached is the Fault Dectection and Dispatch (FDD) activities of Maintenance Control in the Operational Control Center of a prototype MX system. By approaching a highly unstructured problem the design morphology used was able to show clearly the required elements of the problem in their true perspective. Hence the role of the operators and other personnel become clear. In this research the problem was defined and basic FDD requirements identified. A computerized maintenance model was developed and tested, and the elements of the protective structure location were defined for impact upon the emerging FDD system. Three basic scenarios for MX maintenance were identified and 180 candidate systems developed for FDD. A multi-attribute criterion function was approached for the evaluation of the candidate systems. This criterion function will be developed in subsequent research and the optimal candidate chosen analytically. A list of desireable trade studies was developed and subsequent activity will clarify Maintenance Control tasks and information flow.

ACKNOWLEDGEMENTS

This research would not have been possible without the assistance, contributions, and cooperation of many individuals and several agencies.

First the financial support of the Air Force Office of Scientific Research (AFOSR), Air Force Human Resources Laboratory (AFHRL) and Ballistic Systems Office (BSO) are gratefully acknowledged. Dr. Alfred R. Fregly, Life Sciences Directorate (AFOSR/NL) and Dr. William B. Askren AFHRL/ASR were both helpful with their quidance and technical monitoring of the research into the methodology and their help in providing direction. Capt. Thomas Roomsburg, BSO/MNLE and Mr. John Gifford, TRW Systems provided the local coordination with the MX Project and were exceedingly generous in giving their time and effort to help the UH team become knowledgeable quickly with the MX/OCC problem situation.

The research team at the University of Houston was constituted as follows:

1. E. A. Kiessling, Col. USAF (RET), Research Scientist, for his technical and administrative assistance in the operations of the research contract and the actual problem situation.
2. Captain John R. Folkeson, USAF for his assistance in the formulation of the maintenance scenarios and the clarification of maintenance requirements.
3. Dr. Charles Donaghey, Chairman and Professor of Industrial Engineering for his formulation and development of the Computerized Maintenance Study and his help in preparing Appendix A of this report.
4. Dr. Basheer Khumawala, Professor of Systems and Operations Management for his location study in Appendix B of this report.

5. Dr. Nelson Marquina, Assistant Professor of Industrial Engineering, and Dr. Bruce Fiering, Assistant Professor of Industrial Engineering for their help in formulating the approach to the criteria modeling.

6. Kenneth Zingrebe, Research Assistant,
Wen Yuan Lin, Research Assistant,
Malik Putcha, Graduate Student,
for their help in a myriad of acitivites throughout the research.

Benjamin Ostrofsky

Principal Investigator

TABLE OF CONTENTS

ABBREVIATIONS

AFOSR	Air Force Office of Scientific Research
AFHRL	Air Force Human Resources Laboratory
AMF	Alert Maintenance Facility
AOCC	Alternate Operations Control Center
AVE	Aerospace Vehicle Equipment
BMO	Ballistic Missile Office
C^3	Communications, Command, and Control
EWO	Emergency War Orders
FDD	Fault Detection and Dispatch System
FY	Fiscal Year
ILS	Integrated Logistics Support
LED	Light Emitting Diode
LRU	Line Replaceable Unit
MX	Missile X
M^2	Minuteman
OCC	Operational Control Center
OSE	Operations Support Equipment
PLU	Preservation of Location Uncertainty
PS	Protective Structure
PSA	Primary Support Area
SAC	Strategic Air Command
SAF	Security Alert Facility
SAL VER	SALT Verification
SAMSO	Space and Missile Systems Organization
SPO	System Project Office

SMSB	Strategic Missile Support Base
T.O.	Technical Orders
V & E	Vehicle and Equipment

1.0 INTRODUCTION

1.1 Statement of Objectives

1.1.1 Air Force Office of Scientific Research (AFOSR)

The research under this contract (1) represents the attempt to apply a structured decision process (2) to the design of a complex, relatively unstructured requirement in a large USAF system in order to properly consider Human Factors.

1.1.2 Space and Missile Systems Organization (SAMSO)

In order to meet the AFOSR requirement SAMSO identified an area of interest for this research. Specifically, the definition of the Operational Control Center (OCC) activities for processing maintenance status change through dispatch, completion of corrective action, and post dispatch debriefing were identified as the areas to be studied for the MX System. The design morphology was to be applied to the definition of an optimal Fault Detection and Dispatch (FDD) for meeting the needs resulting from these areas of the MX System.

SAMSO further recognized that the utmost latitude in developing solutions was to be afforded the University of Houston in order to develop a more effective and hopefully creative response to meet the FDD requirements.

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[1] Contract No. F-49620-77-C-0116.

[2] Ostrofsky, Benjamin, Design, Planning, and Development Methodology, Prentice-Hall, 1977.

1.2 Background

This research is part of a continuing (3) USAF effort to improve the techniques used for designing aerospace hardware. Specifically, the difficulties of properly emphasizing human resources and logistics factors (4) in the development of Air Force Systems have often created both operational problems in the field and less than desired efficiency in training and maintenance expenditures. Hence the need for the equipment designer to understand the impact of human resources and logistics factors implies a need to assure adequate recognition by all the planning approval agencies of these factors in the design decision structure.

AFOSR grant #77-3148 related the design morphology (2) to other research and established semantics to be used. The morphology provides a decision structure for the development of a technological system which appeared to be highly effective when used to design USAF equipment. The relationship between the semantics of the design morphology and those of USAF were clarified and related to the existing literature in both human factors and engineering design areas. This effort provided a case study in interdisciplinary communications.

[3a] "Morphology of Design of Aerospace Systems with Inclusion of Human Resource Factors," AFOSR Grant 77-3148 (FY 1977).

[b] "Augumentation of Research into Morphology of Design of Aerospace Systems with Inclusion of Human Factors," AFOSR Cont F49620-77-C-0116 (1 Sept. 77- 1 Oct 78).

[c] Op. Cit. (1 Oct. 78 - 30 Sept. 79).

[4] John P. White, Assistant Secretary of Defense, "Manpower Analysis Requirements for Systems Acquisition," Washington, D.C., August 17, 1978.

The major thrust of the FY 78 research (3) was the application of the design structure to a relatively small design problem, the servicing stand for the Emergency Power Unit of the F-16 Aircraft (5). The principal investigator took on the role of advisor to the design engineers at General Dynamics, and by working with these engineers in regular sessions proceeded to apply the morphology successfully. Acceptance of the human factors requirements was dramatically demonstrated by defining a criterion function that required human resource considerations to be combined with hard, engineering data. The ease with which the design reviews were satisfactorily accomplished helped to convince General Dynamic management that the design morphology was indeed effective when properly applied.

In view of the successful application to a small, hardware system, the decision was made to apply the morphology to a larger more sophisticated USAF system. After some review, the problem of processing maintenance status change through dispatch, completion of corrective action, and post dispatch debriefing for the MX Weapon System was approved by SAMSO, AFOSR and the Air Force Human Resources Laboratory (AFHRL).

Due to the magnitude of the MX System and to its status in FY 79, it become apparent that the entire FDD optimization process would not be achieved within one year. Hence this research extends from the definition of needs and requirements to the initial steps in the optimization sequence. Supporting studies in maintenance and facilities location were undertaken to provide additional insight and parameter definitions to the basic FDD

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[5]Ostrofsky, Benjamin, "Application of a Structured Decision Process for Proper Inclusion of Human Resources in the Design of a Power Unit Support Stand," University of Houston, Houston, Texas, September, 1978.

study. Finally, this study was accomplished using the Vertical Shelter concept for the MX. Should another MX concept be implemented very little effort will be lost in applying the content of this study to the new system.

2.0 PROBLEM DEFINITION AND REQUIREMENTS

2.1 Basic Requirements

Initial consideration was given to the definition of the roles and functions of the OCC. Current planning by Strategic Air Command (SAC) for MX/OCC includes the following activities:

1. Monitor force status
2. Communicate force status to higher authority
3. Dispatch and coordinate maintenance activities
4. Receive emergency action messages from higher authority and initiate launch actions as directed
5. Reprogram or retarget missiles
6. Control movement of missile/decoys
7. Monitor physical security status and control security forces
8. Control access to designated areas

The following formal organizations are incorporated into the MX/OCC:

1. Wing Command Post
2. Launch Control Center
3. Maintenance Control
4. Wing Security Control

Development of the FDD will include the activities of Maintenance Control only as well as those activities of the remaining Controls that are necessary to the efficient accomplishment of the Maintenance Control activity within the OCC.

Maintenance Control includes the following:

1. Job, scheduling, and material control for missile maintenance, communication, Civil Engineering, and transportation.

2. Direct line communications capability from each composite area to all interfacing agencies.

3. Monitor Force Status, dispatch and coordinate maintenance activities and missile/decoy movements.

While the primary objective of FDD is to respond to item #3, it is recognized that the interaction of items 1 and 2 have such a direct affect on any FDD system that a detail awareness of the accomplishment of these activities must be considered in its development.

There will exist at least one Alternate OCC (AOCC) which will serve as backup and will possess all the capabilities of the OCC. Delineation of AOCC details, however, will result from other analyses accomplished by SAMSO and SAC, and is mentioned at this point primarily for awareness purposes.

Figure 1 represents the information flow and decision sequence for this research. The input-output analysis, definition of scenarios, concepts and candidate systems, and an initiation of the modeling effort has been accomplished in FY 79. To support these areas of decisions, a maintenance study and a location parameter study have been initiated in order to provide specific inputs to the subsequent optimization efforts for the ensuing activities. These are summarized in Section 3.0, and presented in detail in Appendices A and B.

2.2 Activity Analysis

Figure 2 shows the functional flow of activities require to accomplish the Maintenance Control Function. While this flow is a preliminary one, it represents the top level flow of activity envisioned for the support of the MX force. When the optimal FDD activity sequence is identified a detail definition of the OCC information flow, data requirements, organization and equipment requirements will be provided.

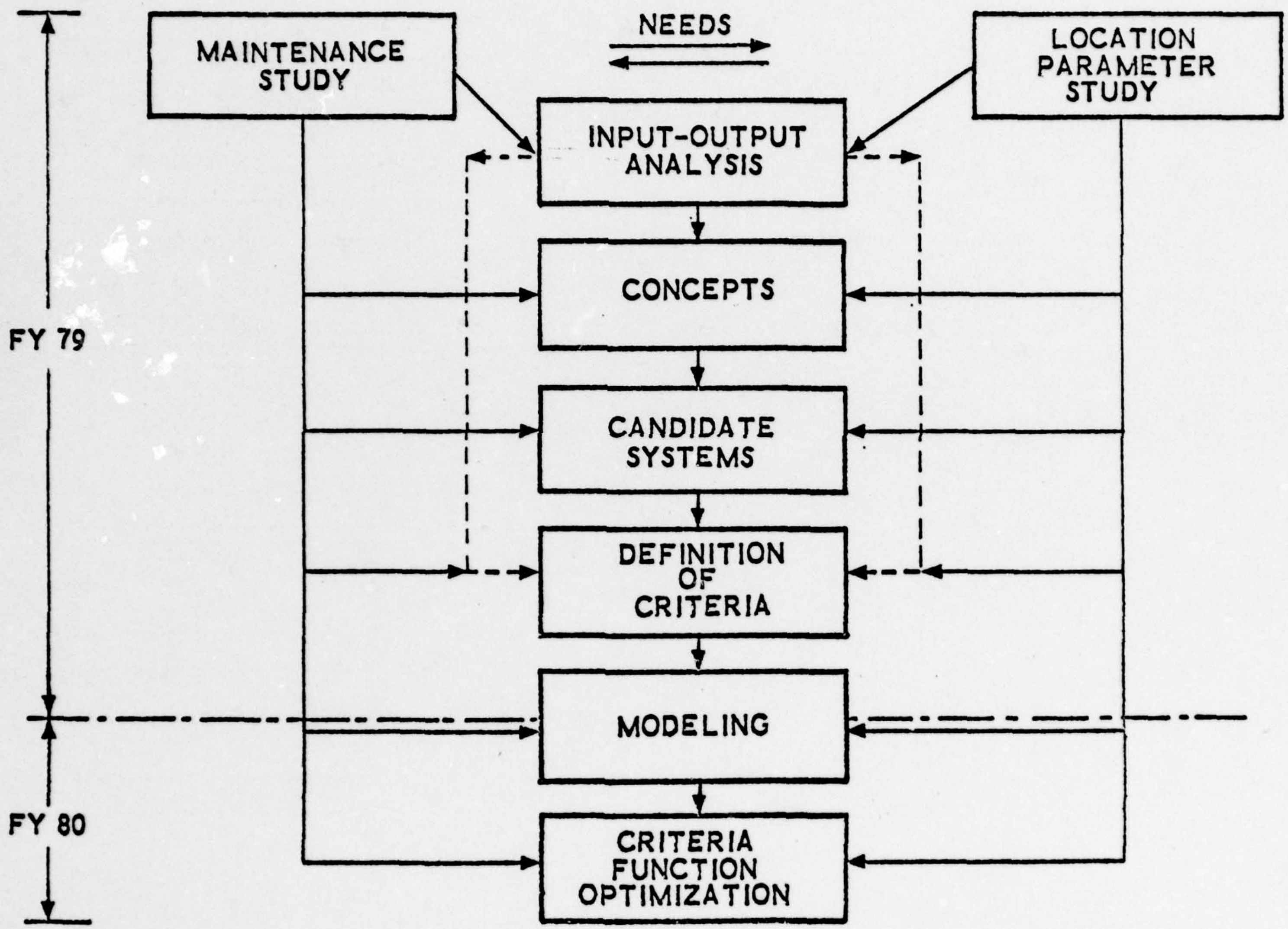

FIGURE 1: STUDY INFORMATION FLOW

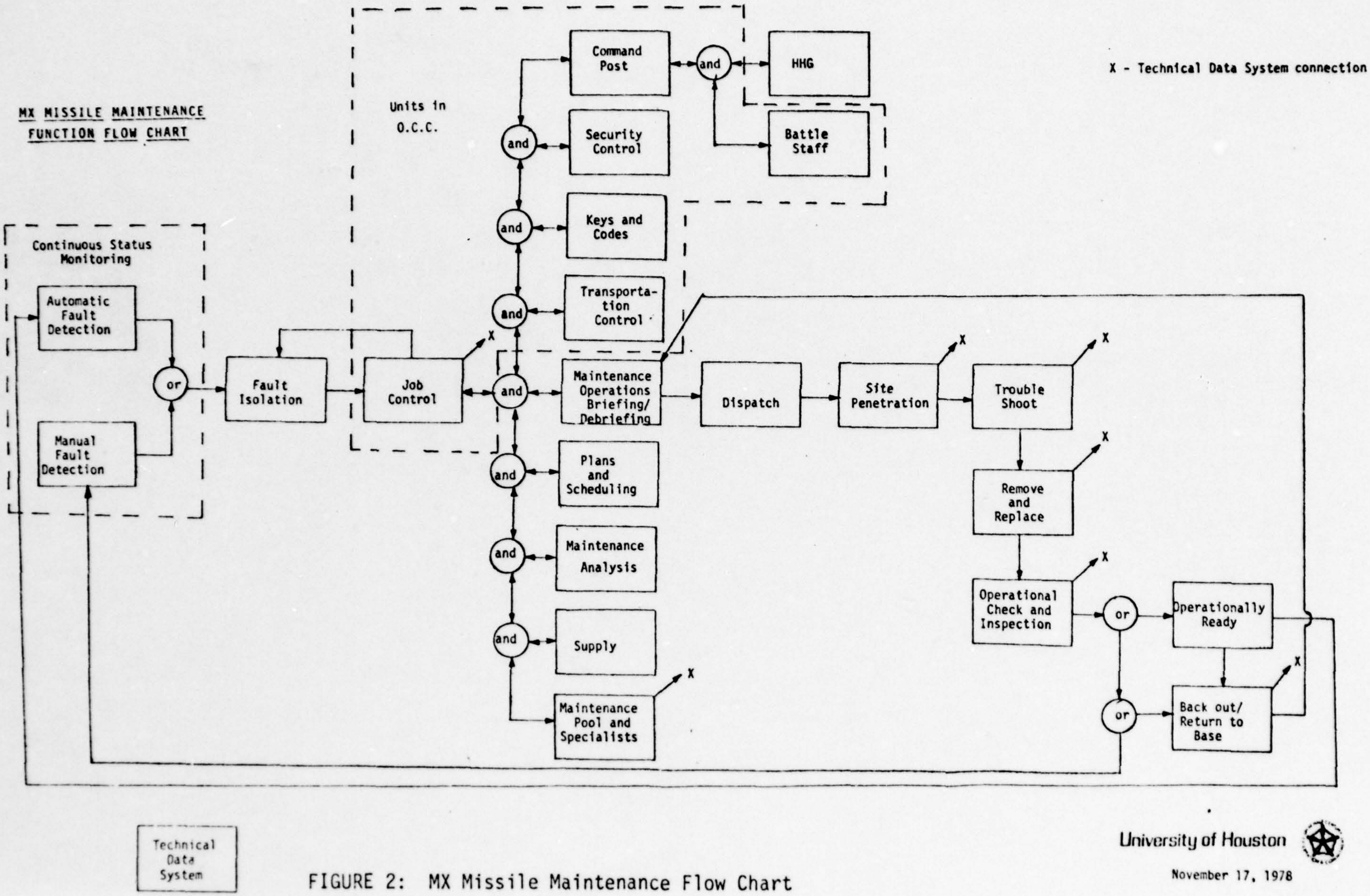

FIGURE 2: MX Missile Maintenance Flow Chart

University of Houston

November 17, 1978

Figure 3 below identifies the broad conditions prevailing as "Inputs" for the FDD:

1.	Monitoring Equipment (Automated)
2.	Software and Procedures for Fault Detection and Analysis
3.	C^3
4.	Flexibility of Dispatch Rules
5.	Maintenance Concept
6.	Monitoring Equipment to be easy to operate and to maintain
7.	Efficient Personnel Training Program
8.	Effective Pipeline for personnel and spares

FIGURE 3: <u>FDD System Input from the MX</u>

While there exist many other areas of input information, figure 3 provides the major set initially considered. Figure 4 below provides the "outputs", i.e., the major conditions that are to be met with an FDD that meets MX requirements.

1.	Each PS monitored at least once every 60 seconds
2.	95% of faults to 1 LRU;
	5% of faults to 4 LRU
3.	Ease of fault definition (high level of automation)
4.	Complete T.O. readily available
5.	T.O. Data easy to use
6.	Efficient notification and dispatch
7.	Maximum utilization of maintenance teams and equipment
8.	Effective skill level mix for team composition
9.	Minimum spares for planned system availability

FIGURE 4: <u>Major FDD System Outputs for MX</u>

3.0 STUDIES AND ANALYSES

3.1 Maintenance Study

The maintenance study has been developing a Monte-Carlo simulation model of the MX maintenance activities. The model has been designed with as much flexibility as possible to permit analysis of a variety of maintenance strategies and scenarios so that maintenance activities will not constrain MX mission accomplishment or growth. The program is modular and allows for additions and modifications with a minimum of disturbance to the previously written code. In order to allow the programs to be as portable and machine independent as possible all programming has been done in standard FORTRAN. Testing of the program at each step was done both on IBM and Honeywell computing systems to ensure portability.

Appendix A contains a description of the model and preliminary results. These results are centered around a hypothetical maintenance scenario which will be varied in subsequent study. This model, being modular, permits additions and changes to include any relevant characteristics desired by the analysts or required by the MX SPO due to program modifications or technological growth.

Initial investigation showed the change in MX force availability for an initial maintenance plan assumed in the development of the simulation (See Figure A-3) when the number of PS in the MX Sector is increased for a constant size maintenance team.

3.2 Protective Structure (PS) Location Impact upon Maintenance

Appendix B contains a description of the current status of the Facilities Location Analysis, and is briefly summarized here. The effectiveness of the OCC internal equipment, personnel, and procedures will depend in large part on the number of PS and their locations. This will influence all maintenance activity and, since this activity is controlled from the OCC, the impact of location variables upon the final Maintenance Control configuration will be pronounced.

Problems in location analysis can be classified into two major categories, first, location on a plane (Continuous); and second, location on a network (Discrete). Location on a plane is characterized by:

1. an infinite solution space; that is the facilities may be located at any point on the plane
2. distance measurement is characterized by:

$$d^2_{ij} = (x_i - x_j)^2 + (y_i - y_j)^2$$

where:

d_{ij} = distance between points i and j

x_i, y_i = coordinates in the rectangular system of the i<u>th</u> point

Location on a network is characterized by:

1. a set of solutions consisting of pre-selected, discrete points on the network

2. distance and/or time measurement along the network where d_{ij} becomes the length (time) of the shortest path from node i to node j

The general mathematical formulation of the network location problem for a single service is represented by:

Minimize $\quad Z = \sum_{i}^{m} \sum_{j}^{n} c_{ij}(x_{ij}) + \sum_{i} F_i(y_i);$ (2)

Subject to: $\quad \sum_{i}^{m} x_{ij} = D_j$ for all j (3)

$\sum_{j} x_{ij} \leq s_i y_i$ for all i (4)

$x_{ij} \geq 0$ for all i and j

$y_i \geq 0$ for all i

where:

x_{ij}	=	flow of products or services supplied from location i to demand area j
y_i	=	O, 1 variable indicating the absence or presence of the facility at candidate location i
$c_{ij}(x_{ij})$	=	cost of supplying products or services from i to j
$F_i(y_i)$	=	cost of establishing and operating the facility at location i
D_j	=	the demand at area j
n	=	number of demand area (j = 1, 2, ..., n)
m	=	number of preselected sites (i = 1, 2, ..., m)

A computer program listing is provided in Appendix B that analyses a typical AMF location problem.

3.3 Impact upon Activity Analysis

The impact of the maintenance study and the location study upon the FDD is readily apparent. By parameterizing the variables associated with the basic requirements of FDD availability and the effectiveness of physical operation of the equipment and the maintenance organization, explicit comparisons can be made from these study outputs upon the various scenarios developed for the FDD activities. The identification of force availability from these studies for a given operating scenario, for instance, provides a relatively accurate, preliminary evaluation of FDD performance. Additionally the accomplishment of the maintenance and location studies provide greatly enhanced insight into the operating problems requiring resolution for the FDD. As a result of this insight a multiple attribute criterion function can be more accurately synthesized from which to construct and analyze a design space for the FDD. Then from this design space FDD alternatives can be evaluated on a consistent performance scale so that the best performing FDD system can be identified and developed.

4.0 DEFINITION OF CONCEPTS

4.1 Basic Scenarios

Figure 5 identifies the basic FDD activity sequence from which assumptions can be made on the nature and location of these activities. Basically the detect function is the recognition of a fault or discrepancy in the missile force including OSE. The preciseness of location (PS assembly, LRU, etc.) is left to the subsequent development of candidate systems. Once a fault is detected, the analysis function consists of the process of defining the nature of the fault, its precise location (if suitable to the concept), the requirements for resolving the fault and the appropriate scheduling of personnel. Dispatch includes the coordination of schedule implementation for command post, job control, transportation, and security. When the maintenance personnel arrive at the PS they clear security requirements ("Interrogate Security") for access to the missile or the associated equipment which may contain the fault. The Maintenance Tasks are accomplished and Verification is obtained by clearing with Maintenance Control. The maintenance crew then proceeds to the next PS or returns to their point of dispatch as a function of the prevailing conditions.

In order to consider adequately all possibilities associated with the Maintenance Control development, consideration was given to providing the task accomplishment (along with proper coordination with the OCC) to three different levels in the Maintenance activities. These are listed:

I Fault detection and analysis in OCC

II Fault detection and analysis in AMF

III Fault detection and analysis in SMSB

Each scenario is envisioned to accomplish fault detection and analysis for the missile force with simultaneous information display at the OCC for

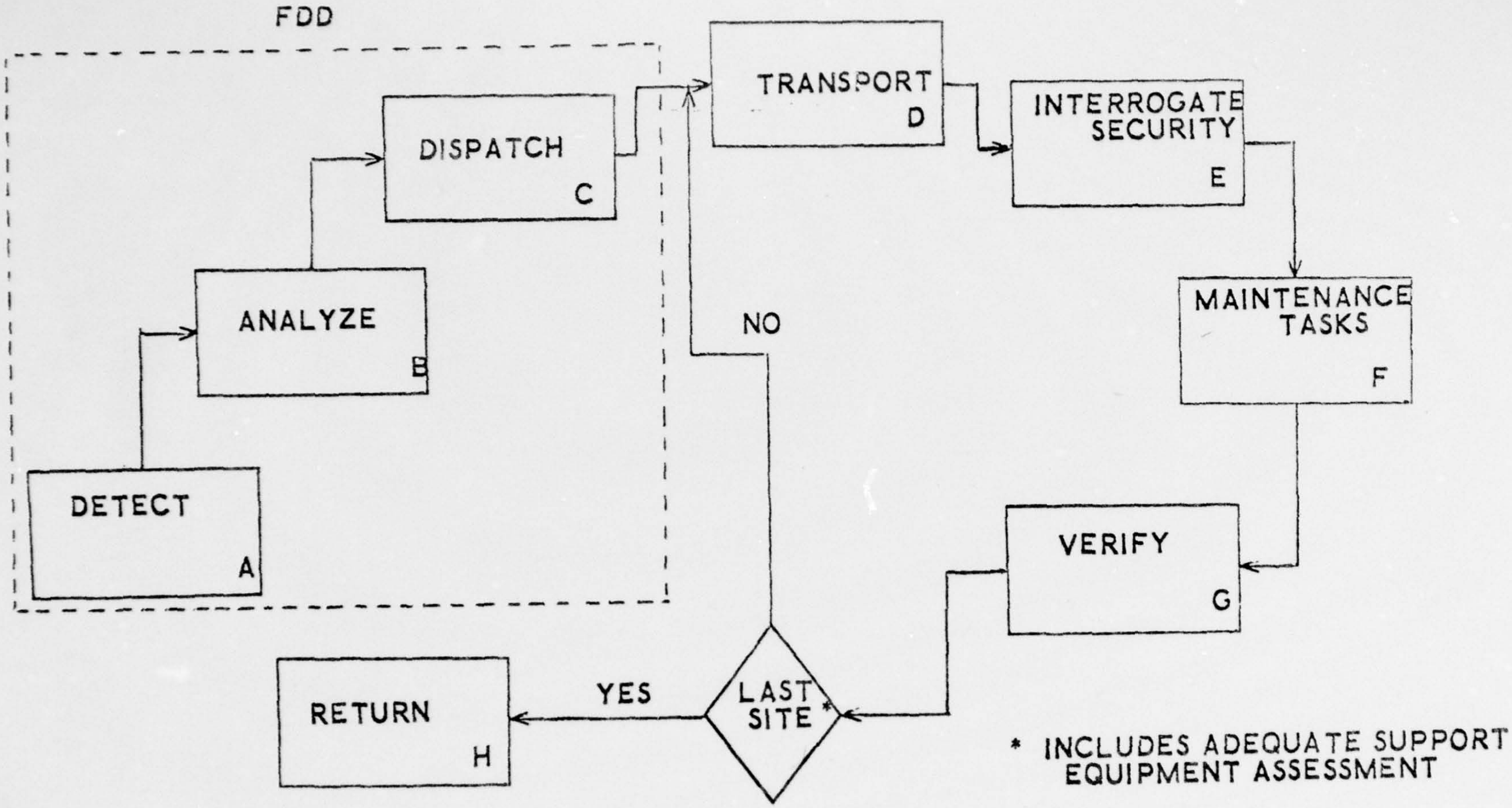

Figure 5 FDD Operations Flow

scenarios II and III. However, it is recognized that the AMF and SMSB will require appropriate readout for any scenario that is developed.

4.2 Scenario I: Fault Detection and Analysis in OCC

In this scenario the primary control and implementation of fault detection and corrective actions is in the OCC. While appropriate coordination with Maintenance Operations, Transportation Control, Plans and Schedules, Supply, and other functions are maintained with proper levels of automation and administrative support, the actual, primary fault detection responsibility lies with the OCC Maintenance Control. In addition, all scheduling and dispatch activities are the responsibility of the OCC. The AMF(s) will be support satellite(s) and not a control activity. The AMF do not repair LRU, only remove and replace as indicated, leaving repair and any additional remove and replace to be accomplished by the SMSB. The distribution system and all AVE and OSE inventory are to be under the direct responsibility and control of the OCC.

4.2.1 Advantages of Scenario I

4.2.1.1 Centralized Control: The complete control of all functions will be within the OCC. All management activities can be effectively accomplished since communication difficulties will be minimized under this approach, primarily because all maintenance control tasks will have close physical proximity to the OCC.

4.2.1.2 Standardized Procedures More Readily Obtained: - Ease of communications and proximity of installations will allow for standardizing the detection, analysis, and dispatch functions.

4.2.1.3 Constant and Accurate Knowledge of PLU: - Because of the ease of communication, and the total centralized control, constant and accurate knowledge of PLU will be achieved. Anomalies in normal operations will be more readily detected.

4.2.1.4 Simpler Distribution System for LRU: - Supply points will be located near the "dispatch" function and all inventory control will be managed directly through OCC.

4.2.1.5 Reduced Number of Pieces of Test Equipment: - Since LRU will be removed and replaced at the PS and AMF, minimal testing is expected at these facilities. The repair capability will be consolidated at the SMSB. Hence, a reduction in number of pieces of test equipment over other scenarios can be expected.

4.2.2 Disadvantages of Scenario I

4.2.2.1 High Automation Levels at OCC: - Since all functions associated with Maintenance Control are to be accomplished within the direct management control of OCC, timely accomplishment of all maintenance control functions for the large number of sites deployed over a large area will require unusually high levels of automation in the systems and equipments used. This may be an advantage operationally, but will add complexity to maintenance and training of personnel.

4.2.2.2 High Levels of Redundancy Required for Automated Scheduling: Because of the large numbers of sites and missiles and the requirements for scheduling maintenance teams, spares, vehicles, and their associated requirements, automated techniques will be required for scheduling teams and coordinating with Transporation Control, determining the availability of spares and other maintenance requirements that are associated with FDD. The availability of scheduling will be vital and hence redundancy will be required in the scheduling system to assure the proper level of system performance.

4.2.2.3 Effective Span of Control over Dispatch Teams will be Difficult: While maximum automation of maintenance control functions will be required, the effect of centralizing all control in OCC will be to create difficulties in proper control over other personnel, inventory, and transportation areas. Hence a disadvantage of having all control in the OCC is probably reduced effectiveness over the dispatch function.

4.2.2.4 Large Number of Teams Controlled from OCC: - Since all functions are concentrated in the OCC, the job of controlling all maintenance teams dispatched will rest with Maintenance Control at the OCC. Hence an increased work load over remote facility control of these maintenance teams will exist, thus compounding the local OCC management problem.

4.3 Scenario II: Fault Detection and Analysis in AMF

This scenario places primary control of Fault Detection and Analysis functions in the AMF. While OCC still retains notification and query capability, the AMF will accomplish analysis, dispatch, and scheduling functions. Depending on the nature of the team, team training, and possibly team formation, fault detection and analysis could be accomplished at the SMSB.

Under this scenario the maintenance role of AMF is expanded to include intermediate LRU repair and, since AMF has prime responsibility for fault detection and analysis, high levels of coordination must exist between it and OCC in all required areas.

4.3.1 Advantages of Scenario II

4.3.1.1 Reduced Span of Control over all Maintenance Activities: While OCC will be the major coordinating installation between Maintenance Control and the remaining OCC functions, the actual responsibility for the accomplishment of FDD functions will be with the AMF. Hence the administrative control functions of detecting, analyzing, and dispatching will be accomplished by the responsible AMF for a given area. Hence the OCC Span of Control will be limited to missile status and executive control of AMF and SMSB.

4.3.1.2 Easier Transition from a Minuteman (M^2) Organizational Structure: This scenario closely parallels current M^2 organization, hence transition problems of maintenance personnel may be significantly reduced.

4.3.1.3 Reduces OCC Staff Requirement: Since executive control will reside with the OCC while line functions will be in the AMF, the staff requirement for OCC will be materially reduced over Scenario I.

4.3.1.4 Decreased Personnel Scheduling Complexity: Each AMF will be responsible for its own sector, hence have a smaller number of sites to monitor.

4.3.2 Disadvantages of Scenario II

4.3.2.1 Coordination of Wing Requirements is Difficult: Coordination among AMF becomes increasingly difficult with increasing numbers of AMF. Some of this problem would be resolved by adequate console readout from each AMF in the OCC and equipment complexity in the OCC is increased.

4.3.2.2 Increased Test Equipment Costs: Test equipment costs will increase with the number of AMF since each AMF will require duplication of that equipment necessary for intermediate level maintenance.

4.3.2.3 Variable Supply Costs: Buffer inventory requirements will exist for each AMF. However, the demand requirements for each LRU will decrease at an AMF as the number of AMF increase. Hence spares inventory costs will vary with the number of AMF, but will probably be lower than Scenario I when a large number of AMF exist, since there should be total decrease in total pipeline requirements.

4.3.2.4 Increased Manning for Maintenance Control: OCC Maintenance Control will require staffing for its executive functions as will each AMF in the field. There will be duplicate requirements for each AMF and hence increased manning for the total organization when all staffing is considered.

4.3.2.5 Decreased Control over Maintenance By Maintenance Commander: The maintenance commander will be in the OCC while the line activities will be in the AMF. Hence indirect control will exist through communication with each AMF.

4.3.2.6 Reduced Economy of Scale in LRU Repair: For that repair accomplished at the AMF there will be a reduced economy of scale in LRU repair directly related to the number of AMF.

4.3.2.7 Increased Pipeline Complexity: This will exist because of the multiple location requirements imposed by the replacement requirements of the AMF, and will increase in complexity with the number of AMF.

4.3.2.8 More Command Positions: AMF Commanders will have greater responsibility than in Scenario I, and, while this may have operational advantages, it places a burden on personnel selection resulting from increased responsibilities.

4.3.2.9 Increased C^3 Complexity: The C^3 network will be enhanced over Scenario I because of the greater autonomy of the AMF while under the control of the OCC.

4.4. Scenario III: Fault Detection and Analysis in SMSB

Under this scenario functional maintenance control exist at the SMSB with fault detection information simultaneously provided to OCC. SMSB actually accomplishes the tasks of analyzing, scheduling and dispatching. However, maintenance control command remains in OCC. Light intermediate maintenance occurs at the AMF and total intermediate and most depot maintenance occurs at SMSB.

4.4.1 Scenario III Advantages

4.4.1.1 All Maintenance Management at One Location: Since control exists at the most detail level of maintenance the management of these activities will have more direct control due to physical proximity and better communication.

4.4.1.2 Economies of Expertise and Skill Levels: Since all levels of maintenance activities exist at one location, more effective use of hard-to-acquire skills can be achieved with significant possibility for reducing the number of these personnel that are required.

4.4.1.3 Centralized Scheduling and Control: With all maintenance levels at one location, scheduling of teams and replacement of LRU becomes easier, implying potentially lower levels of LRU inventory along with reduced manning requirements.

4.4.1.4 Centralized Maintenance Decision Making: With control of maintenance in SMSB, detection, and analysis of faults should become more efficient thus implying improved accuracy in determination of team and inventory requirements.

4.4.1.5 Reduced Test Equipment & Inventory Requirements: Due to the combination of Maintenance Control functions with that of one AMF and the SMSB there exists the possibility for reduction in test equipment required at that location. LRU inventory requirements can be minimized since supply will support the SMSB, AMF and the dispatch function so that only one buffer inventory is required instead of up to three for separate installations.

4.4.1.6 Limited Location Knowledge: Because of the larger concentration of personnel at one location, the scheduling of teams to limit team awareness to 2% or less of the installation should become easier.

4.4.1.7 Reduced Span of Control: This exists because of the reduced communication distances and the ability to resolve force maintenance problems within the SMSB since both staff and line functions of Maintenance Control exist in the same organization.

4.4.2 Scenario III Disadvantages

4.4.2.1 Parallel Detection Capability Requirement: Both OCC and SMSB will require a parallel fault detection requirement since OCC will have command responsibility for maintenance control.

4.4.2.2 Increased Management Problems: Since OCC will be physically separated from Maintenance Control clear lines of authority and responsibility will be more difficult to establish.

4.4.2.3 PLU Compliance Problem: Since AMF maintenance personnel will be physically close to SMSB (and possibly to OCC) there will be increased difficulty in maintaining the required limited exposure knowledge to any given team for extended time intervals.

4.5 Comparison of Scenarios

This section provides a preliminary, heuristic evaluation of the effectiveness of each area of logistics support as it is affected by the respective scenario. The respective areas are defined as:

1. Maintenance Planning - The ability of the scenario to aid in the definition of support requirements and plans for maintenance to satisfy operational goals.

2. Support and Test Equipment - The ability of the scenario to assure the availability of required tools and test equipment to perform maintenance functions at all specified locations.

3. Supply Support - The ability to provide timely and adequately spares, repair parts, and special supplies to satisfy operations and maintenance functions.

4. Transportation and Handling - The ability to provide transportability and selection of optimum transportation, handling, packaging, and preservation methods.

5. Technical Data - The ability to identify and record for on-call use of technical information necessary for efficient operation and support of equipment.

6. Facilities - The ability to identify, select, and program facilities to accomplish the support mission.

7. Personnel and Training - The ability to identify and to program skills, personnel, and training to satisfy maintenance and operations requirements.

8. Relative Costs - The cost of the given scenario when accomplished, relative to the others.

9. Management Data - The ability to selectively identify and use information and control systems for the collection and dissemination of performance data necessary for support management.

Figure 6 presents an heuristic comparison of the three scenarios as viewed by this research team. The numbers shown in the table represent the relative ranking of the respective scenario for the given support element effectiveness with respect to the remaining two scenarios. This ranking is highly tenuous, and can vary dramatically with variations in each scenario. For example, with a large number of AMF Scenario III would probably be more effective than Scenario II for "Technical Data", but as the number of AMF decrease for the missile wing Scenario II would probably approach Scenario III in effectvieness. A tentative, heuristic comparison of the three scenarios indicates the desirability sequence of the scenarios to be III, I, II, with Scenario III about twice as effective in the logistics support area as Scenario II, and about 1.5 times as effective as Scenario I. Further Scenario I is one-third more effective in the logistics areas than Scenario II. Since these evaluations are highly subjective, they should be considered as preliminary subject to further evaluation.

		SCENARIOS		
		I (OCC)	II (AMF)	III (SMSB)
1.	Maintenance Planning	2	3	1
2.	Support & Test Equipment	3	2	1
3.	Supply Support	1	3	2
4.	Transportation & Handling	3	2	1
5.	Technical Data	3	2	1
6.	Facilities (OCC, AMF, SMSB)	1	3	2
7.	Personnel & Training	2	3	1
8.	Relative Costs	1	3	2
9.	Management Data (Information System)	2	3	1

(1 is most desireable)

Figure 6: Relative Effectiveness of Each Scenario For Each Integrated Logistics Support Area

5.0 DEFINITION OF CANDIDATE SYSTEMS

5.1 Fundamental Approach

Figure 5 identified 8 basic tasks associated with accomplishing FDD functions. These are:

1.	Detect	5.	Interrogate Security
2.	Analyze	6.	Maintenance Tasks
3.	Dispatch	7.	Verify Completion
4.	Transport	8.	Return (to base or to another site)

Section 4.0 described three basic scenarios for the operations of Maintenance Control. These scenarios provide the range of alternative options toward the operations of FDD, and hence meet the requirements of the design morphology as "concepts"(6). Explicitly, then the flow of activities in figure 5 establishes the concept as it relates to each respective scenario. Hence, this study will consider each of the scenarios described in section 4.0. A description is provided below (Sections 5.2.1 through 5.2.8) of the fundamental tasks listed above.

5.2 Development of Candidate Systems

A candidate system, by definition (7) includes each of the activities described in Section 5.1. Hence, by identifying alternative methods for accomplishing each activity, any combination of one method from each respective activity would constitute a candidate system. This section develops the alternatives for each activity.

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(6) Ostrofsky, Benjamin, <u>Design, Planning and Development Methodology</u>, Prentice-Hall, 1977, (Pg. 47).

(7) Ibid.

5.2.1 Detect Function: This is the activity in the OCC, AMF, SMSB, or other organizations requiring notification (or readout of the occurance of a fault in the missile force. This function will probably be an automatic indication of some sort and be on simultaneously readout with the responsible AMF for Scenario II or the SMSB for Scenario III (or possibly all three depending on the chosen candidate system).

Alternatives for the Detect function are:

1. Go-no-go Light Display
2. L.E.D. display
3. Audio alarm
4. Flashing status display
5. Simultaneous display with some combination of all 4 alternatives

5.2.2 Analyze Function

Given that a fault has been detected to the LRU level, the Analyze Function includes the determination of:

1. Location of the fault to the lowest equipment level required for the particular maintenance concept.
2. Location of the Protective Structure
3. Fault criticality (i.e. safety or PLU criticality determination of missile launchability, etc.)
4. Preventive/corrective replacement equipment
5. Required team specialities for maintenance action
6. Estimated maintenance time at the PS.
7. Alerting Transportation: Control, security control and other dispatch function organizations.

Alternatives for analyzing the fault will be largely determined by the particular concept and candidate system that is implemented. However the Analyze Function can be:

1. Localized to the Subsystem Level
2. Localized to the LRU level
3. Some combination of 1 & 2
4. Related to Performance Threshold level

The latter implies the arbitrary determination of acceptable readouts from a given LRU (for example IMU precession rates). Changing the threshold level will affect the rate at which faults are identified.

5.2.3 Dispatch Function

This function accomplishes:

1. scheduling of proper team personnel
2. scheduling of vehicles and equipment
3. maintenance of the team status in correcting the fault
4. coordination with the detect and analysis functions
5. communication with dispatched teams.

Alternatives for this function are:

1. Organizing for specialized skills in each team to respond to a given fault
2. Organizing for a standard skill mix for each team with specialists
3. Organizing for a standard skill mix with technicians who are each multi-skilled

5.2.4 Transport Function

This function accomplished the actual transport of the maintenance team with the required equipment for correcting the analyzed fault. Since available vehicles will be used for this function, including backup from SMSB and other AMF and airborne vehicles if required, this function will have essentially the same alternatives for all candidate systems.

5.2.5 Interrogate Security

This activity is the means by which the maintenance crew achieves its security checks prior to accessing the PS and its support equipment.

5.2.6 Maintenance tasks

These include all corrective tasks required to remove the fault that has been identified at OCC plus any preventive tasks that may be identified by the Analysis Function and/or the Maintenance Team at the PS.

5.2.7 Verification Function

These activities include:

1. Verification of complete corrective action for fault removal both at OCC and the Dispatch function organization
2. Verification of security requirements upon egress from PS.
3. Determination of whether to return to base or to proceed to another PS for removal of another fault

5.2.8 Return Function

The maintenance team proceeds to another PS for removal of another fault or returns to base.

5.3 The Candidate System Set

The functions of Transport, Interrogate Security, Maintenance Tasks, Verification and Return (Sections 5.2.4 to 5.2.8) are all considered to be constant for all scenarios and their respect candidate systems. Hence, the candidate systems synthesized include the Detect, Analyze, and Dispatch Functions only, since the others, with the exception of Maintenance Tasks will remain relatively constant -- and, hence, will not influence the choice of the optimal candidate system significantly.

Figure 7 illustrates a typical alternative combination of functions or "candidate system". Since there are 5 alternative for Fault Detection, 4 for Analyze, and 3 for Dispatch, there are 60 Candidates that will require evaluation for each of 3 scenarios, or 180 candidate systems in the set (see Figure 8).

A	B	C
DETECT FUNCTION	ANALYZE FUNCTION	DISPATCH FUNCTION
4. Flashing status Display	2. Localize to LRU	3. Make-up Specialized Team After Fault Analysis

FIGURE 7: TYPICAL CANDIDATE SYSTEM

	A	B	C
SCENARIOS	DETECTION	ANALYZE	DISPATCH
I	1	1	1
II	2	2	2
III	3	3	3
	4	4	
	5		

180 TOTAL CANDIDATE SYSTEMS TO BE ANALYZED

Figure 8 The set of Candidate Systems

6.0 DEFINITION OF CRITERIA AND PARAMETERS

6.1 Identification of Criteria

In order to evaluate the potential performance of the candidate systems criteria must be explicitly identified.(8) Since the FDD is only one of many "sub-systems" in the MX program, criteria pertaining to the entire MX also pertain to the FDD, however, within this constraint more explicit measures must be identified. Hence a questionnaire was developed (see Part I Appendix C).

The questionnaire initially suggested these criteria:

1. Availability
2. Comparative Costs
3. Team Utilization
4. Vehicle Utilization
5. Strategic Arms Limitation Verification (SAL VER)
6. Preservation of Location Uncertainty (PLU)

Opportunity was provided for the respondants to add, delate, or change criteria. Ten key individuals identified by SAMSO/MNLE were given the questionnaire, and the following criteria resulted:

1. Availability: - the MX force operational availability
2. Comparative Costs: - the cost of a given candidate system relative to a standard cost
3. Team Utilization: - the level of activity of the maintenance teams measured as a fraction of their available time or other suitable metric.

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(8) Op. Cit. (pp. 80-85).

4. Vehicle and Equipment (V & E) Utilization: the level of activity of all vehicles and equipment necessary for MX force readiness measured as a fraction of their available time or other suitable metric.
5. Preservation of Location Uncertainty: the ability of the candidate system to preserve location uncertainty.
6. Strategic Arms Limitation Verification (SAL VER) The ability of a candidate system to support SAL VER as identified by an acceptable metric.

These criteria will be used to explicity evaluate the performance of the 180 candidate systems.

6.2 Definition of Relative Importance

Part II, Appendix C, provided the opportunity for respondants to identify their opinion regarding the relative important of each criterion. Figure 9 shows the response to this questionnaire. SAL VER presented the only bimodal response, that is, the ratings were all at 7 or above or they were at 1 or below. After consultation, the high values were eliminated since SAL VER was considered by SAMSO to be a total MX criterion, and that conditions imposed by SAL VER would provide higher constraints upon candidate system performances than it would as a direct criterion on FDD performance evaluation.

i	Criterion, x_i	1	2	3	4	5	6	7	8	9	10
		Respondants to Questionnaire									
1.	PLU	10	10	10	10	8	10	10	9.5	10	9
2.	Availability	9	6	10	10	8	9	9.5	10	10	10
3.	Comparative Costs	6	9	6	4	1	8	5.5	9	6	5
4.	Team Utilization	7	8	10	5	6	0	6.5	5	7	7
5.	V & E Utilization	7	8	10	4	6	0	6.5	0	6	8
6.	SAL VER	2	10	0	8	7	7	0	0	1	10

FIGURE 9: Raw Data Responses to Questionnaire

i	x_i	Mean Ranking	a_i
1.	PLU	9.650	0.213
2.	Availability	9.150	0.219
3.	Comparative Costs	7.895	0.189
4.	Team Utilization	7.554	0.181
5.	V. & E. Utilization	6.938	0.166
6.	SAL VER	0.600	0.014
		41.787	1.000

FIGURE 10: TABLE I - Design Criteria, $\{x_i\}$ and Their Respective Relative Weights, $\{a_i\}$

(Op. Cit. p. 83)

6.3 Identification of Criterion Elements

In order to approach the quantitative estimates of the criteria, a set of "elements" is identified for each. Figures 11 through 16 accomplish this function (9) and list the elements considered important to the evaluation of each respective criterion. Since this list of elements is preliminary, additions and deletions can be expected in the modeling process.

Changes or modification to Table II or to its elements can be expected as the analyses develop.

6.4 The Parameter Set

Figure 17 (Table III) (10) has arranged the elements of Table II in a form more suitable to begin the modeling effort. Each parameter, y_k, shown in the left column has been identified for each respective submodel in which it occurs. Hence the modeling process now has a "check list" against which to insure completeness of the ensuing analytical activities.

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[9] Op. Cit. pg. 88-91.

[10] Op. Cit. pg. 93.

x_1 PLU

Submodel
Number of Personnel
Number of Vehicles, Equilpment & Facilities
Task Time
Frequency of Action

ELEMENT: Number of AMF
Number of SMSB
Number of multiple skill team
Number of inspection team
Number in AVE moving team
Number in OSE moving team
Number in OSE R/R team
Number in C^3/Security repair team
Number in AVE R/R team
Number of helicopters
Number of vans
Number of transporters
Number of PS
Number of site visits per van per day
Number of site visits per transporter per day
Number of missiles emplaced
Area (total & usuable)
Time to enter/exit site
Time to emplace OSE
Time to emplace AVE
Time to remove OSE
Time to remove AVE
Time to inspect OSE
Time to inspect AVE
Capability to override maintenance computer
Time to R/R AVE
Time to R/R OSE
Security reaction time

Figure 11: PLU Criterion Elements
(Table II, Op. Cit. p. 88)

x_2, AVAILABILITY

Submodel

- Alert time
- Travel Time
- Task Time
- Number of Personnel
- Number of Veh./Equip./Fac.

ELEMENT:

Number of AMF
Number of SMSB
Number of PS
Number of helicopters
Number of vans
Number of transporters
Number of LRU per AVE
Number of LRU per OSE
Number of LRU per RSE
Number of site visits per van per day
Number of site visits per transporter per day
Number of multiple skill team
Number of inspection team
Number of AVE moving team
Number of OSE moving team
Number of missiles emplaced
Number of C^3/Security repair team
Number of AVE R/R team
Number of OSE R/R team
Number of missiles emplaced
Area (total & usable)
Time to emplace AVE
Time to emplace OSE
Time to remove AVE
Time to remove OSE
Time to inspect OSE
Time to enter/exit site
Total number of OSE failure
Total number of OSE no launch failure
Total number of AVE failure
Total number of AVE no launch failure
Failure rate/LRU/AVE
Failure rate/LRU/OSE
Failure rate/LRU/RSE
Failure rate/van
Failure rate/transporter
Failure rate/helicopter
Total number of van failure
Total number of transporter failure
Total number of helicopter failure
Time to repair RSE
Time to R/R AVE
Time to R/R AVE
Time to R/R OSE
Speed of Van
Speed of Transporter
Speed of helicopter
Number RSE repair team
Distance between PS
Security reaction time
Distance from AMF to PS

Figure 12: Availability Criterion Elements
(Table II, Cont.)

x_3, COST, COMPARATIVE*

Submodel	Number of Personnel
	Number of veh./equip./fac.
	Task time
	Testing, operating and spare cost

ELEMENT:

Number of AMF
Number of SMSB
Number of PS
Number of vans
Number of transporters
Number of helicopters
Number of missiles emplaced
Number of OSE R/R team
Number of LRU/AVE
Number of LRU/OSE
Number of LRU/RSE
Time to emplace AVE
Time to emplace OSE
Time to remove AVE
Time to remove OSE
Time to R/R AVE
Time to R/R OSE
Time to inspect AVE
Time to inspect OSE
Time to enter/exit site
Number of multiple skill team
Number of inspection team
Number of AVE moving team
Number of OSE moving team
Number of AVE R/R team
Number of C^3/Security repair team
Number in AVE moving team
Number in OSE moving team
Number in Ose R/R team
Number in C^3/Security repair team
Time to repair RSE
Number in RSE repair team
Number in AVE R/R team
Security reaction time
Cost per van
Cost per transporter
Cost per helicopter
Number of RSE repair team
Personnel supporting cost such as medical, etc.
Road materials
Safety of equipment
Failure rate/LRU/AVE
Failure rate/LRU/OSE
Failure rate/LRU/RSE
Failure rate/van
Failure rate/transporter
Failure rate/helicopter
Total number of RSE failure
Time to repair RSE
Total number of van failure
Total number of transporter failure
Total number of helicopter failure
Speed of van
Speed of transporter
Speed of helicopter
Total number of AVE failure
Total number of AVE no launch failure
Total number of OSE failure
Total number of OSE no launch failure
Personnel cost per OSE R/R team
Personnel cost per AVE R/R team
Personnel cost per multiple skill team
Personnel cost per OSE moving team
Personnel cost per AVE moving team
Personnel cost per inspection team
Personnel cost per C^3/security repair team
Personnel cost per RSE repair team

*Ratios to a standard candidate system or the A.F. cost model will be used where needed instead of absolute costs or numbers.

FIGURE 13: Comparative Cost Criterion Elements (Table II, Cont.)

x_4, TEAM UTILIZATION	
Submodel	Number of Personnel Task Time Total time available (Team) Frequency of Action Travel time
ELEMENT:	Number of AMF Number of SMSB Number of PS Number of vans Number of transporters Number of helicopters Number of LRU/AVE Number of LRU/OSE Number of LUR/RSE Number of multiple skill team Number of AVE moving team Number of OSE moving team Number of inspection team Number of OSE R/R team Number of C^3/Security repair team Number of missiles emplaced Time to emplace AVE Time to emplace OSE Time to remove AVE Time to remove OSE Time to repair AVE Time to repair OSE Time to inspect AVE Time to inspect OSE Time to enter/exit site Failure rate/LRU/AVE Failure rate/LRU/OSE Failure rate/van Failure rate/helicopter Total number of RSE failure Total number of van failure Total number of transporter failure Total number of helicopter failure Time to repair RSE Speed of van Speed of transporter Speed of helicopter Number of AVE R/R team Number of RSE repair team Time to repair RSE Security reaction time Number hrs./day/man Number days/base period

Figure 14: Team Utilization Criterion Elements (Table II, Cont.)

x_5, VEHICLE & EQUIPMENT UTILIZATION

Submodel	Number of vehicle/equipment/facilities Task time Total time available (VE) Frequency of Action Travel time
ELEMENT	Number of AMF Number of SMSB Number of PS Number of vans Number of transporters Number of helicopters Number of LRU/AVE Number of LRU/OSE Number of LRU/RSE Number of multiple skill team Number of AVE moving team Number of OSE moving team Number of inspection team Number of OSE R/R team Number of C^3/Security repair team Number of AVE R/R team Time to emplace AVE Time to emplace OSE Time to remove AVE Time to remove OSE Time to R/R AVE Time to R/R OSE Time to inspect AVE Time to inspect OSE Time to enter/exit site Failure rate/LRU/AVE Failure rate/LRU/OSE Failure rate/van Failure rate/transporter Failure rate/helicopter Total number of RSE failure Total number of van failure Total number of transporter failure Total number of helicopter failure Time to repair RSE Speed of van Speed of transporter Speed of helicopter Number RSE repair team Time to repair RSE Failure rate LRU/RSE Security reaction time Number hrs./day/van Number hrs./day/transporter Number days/base period

Figure 15: Vehicle & Equipment Utilization Criterion
(Table II, Cont.)

x_6, SALT VERIFICATION

ELEMENTS:	Number of PS
	Distance between PS
	Area (total & usable)
	Time to emplace AVE
	Time to emplace OSE
	Time to remove AVE
	Time to remove OSE
	Time to enter/exit site
	Number of multiple skill team
	Number of AVE moving team
	Number of OSE moving team
	Nubmer of transporters
	Number of vans
	Capability to override computer
	Number of missiles emplaced
	Number of minutes for Soviet satellite window
	Number of Soviet satellites

Figure 16: SAL VER Criterion Elements
(Table II, Cont.)

FIGURE 17

(see foldout inside back cover)

PARAMETERS y_x	x_1 PLU					x_2 AVAILABILITY						x_3 COST, COMPARATIVE						x_4 TEAM UTILIZATION						x_5 VEHICLE & EQUIP UTILIZATION						x_6 SALT VERIFICATION
	NO OF PERSONNEL (Z_i)	NO OF VEH/EQUIP/FAC (Z_i)	TASK TIME (Z_i)	$x_1 = f_1(y_x)$	FREQ OF ACTION (Z_i)	NO OF PERSONNEL (Z_i)	NO OF VEH/EQUIP/FAC (Z_i)	TASK TIME (Z_i)	ALERT TIME (Z_i)	TRAVEL TIME (Z_i)	$x_2 = f_2(y_x)$	NO OF PERSONNEL (Z_i)	NO OF VEH/EQUIP/FAC (Z_i)	TASK TIME (Z_i)	TESTING, OPERAT & SPARE COST	$x_3 = f_3(y_x)$	TRAVEL TIME (Z_i)	NO OF PERSONNEL (Z_i)	TASK TIME (Z_i)	TOTAL TIME AVAILABLE (TEAM)	FREQ OF ACTION (Z_i)	$x_4 = f_4(y_x)$	TRAVEL TIME (Z_i)	NO OF VEH/EQUIP/FAC (Z_i)	TASK TIME (Z_i)	TOTAL TIME AVAILABLE (V/E)	FREQ OF ACTION (Z_i)	$x_5 = f_5(y_x)$	TRAVEL TIME (Z_i)	$x_6 = f_6(y_x)$
NUMBER OF PERSONNEL (Z_i)	✓					✓						✓						✓												
NUMBER OF VEH./EQUIP/FAC. (Z_i)		✓					✓						✓											✓						
TASK TIME (Z_i)			✓					✓						✓					✓						✓					
ALERT TIME (Z_i)									✓																	✓				
TRAVEL TIME (Z_i)										✓							✓						✓						✓	
TOTAL TIME AVAILABLE (TEAM) (Z_i)																				✓										
TOTAL TIME AVAILABLE (V.E.) (Z_i)																										✓				
TESTING, OPERATING, SPARE COST (Z_i)															✓															
FREQ OF ACTION (Z_i)					✓																✓						✓			
NUMBER OF AMF	✓	✓			✓	✓	✓					✓	✓					✓			✓						✓			
NUMBER OF SMSB'S	✓	✓			✓	✓	✓					✓	✓					✓		✓	✓			✓			✓			
NUMBER OF MULTIPLE SKILL TEAM	✓					✓						✓						✓		✓										✓
NUMBER OF INSPECTION TEAM	✓					✓						✓						✓		✓										
NUMBER OF AVE MOVING TEAM	✓					✓						✓						✓		✓										✓
NUMBER OF OSE R/R TEAM	✓					✓						✓						✓		✓										✓
NUMBER OF C3/SECURITY REPAIR TEAM	✓					✓						✓						✓		✓										
SIZE OF MULTIPLE SKILL TEAM	✓					✓						✓						✓		✓										
SIZE OF INSPECTION TEAM	✓					✓						✓						✓		✓										
SIZE OF AVE MOVING TEAM	✓					✓						✓						✓		✓										
SIZE OF OSE MOVING TEAM	✓					✓						✓						✓		✓										
SIZE OF OSE R/R TEAM	✓					✓						✓						✓		✓										
SIZE OF C3/SECURITY REPAIR TEAM	✓					✓						✓						✓		✓										
NUMBER OF AVE R/R TEAM	✓					✓						✓						✓		✓										
NUMBER OF HELICOPTERS		✓					✓						✓											✓		✓				
NUMBER OF VANS		✓					✓						✓											✓		✓				✓
NUMBER OF TRANSPORTERS		✓					✓						✓											✓		✓				✓
NUMBER OF PS					✓				✓												✓						✓			✓
NUMBER OF SITE VISITS/VAN/DAY		✓					✓						✓		✓									✓		✓				
NUMBER OF SITE VISITS/TRANSPORTER/DAY		✓					✓						✓		✓									✓		✓				
NUMBER OF MISSILES EMPLACED					✓				✓						✓						✓						✓			✓
DISTANCE BETWEEN PS										✓							✓						✓						✓	✓
AREA (TOTAL & USABLE)					✓						✓					✓					✓						✓			✓
TIME TO ENTER/EXIT SITE			✓					✓						✓					✓						✓					✓
TIME TO EMPLACE AVE			✓					✓						✓					✓						✓					✓
TIME TO EMPLACE OSE			✓					✓						✓					✓						✓					✓
TIME TO INSPECT AVE			✓					✓						✓					✓						✓					
TIME TO INSPECT OSE			✓					✓						✓					✓						✓					
TIME TO REPAIR AVE			✓					✓						✓					✓						✓					
TIME TO REPAIR OSE			✓					✓						✓					✓						✓					
TIME TO REPAIR RSE			✓					✓						✓					✓						✓					
CAPABILITY TO OVERRIDE COMPUTER				✓																										✓
NUMBER OF LRU/AVE					✓				✓						✓						✓						✓			
NUMBER OF LRU/OSE					✓				✓						✓						✓						✓			
NUMBER OF LRU/RSE					✓				✓						✓						✓						✓			
PERSONNEL SUPPORTING COST																✓														
ROAD MATERIALS															✓															
SAFETY OF EQUIPMENT															✓	✓														
FAILURE RATE/LRU/AVE					✓				✓						✓						✓						✓			
FAILURE RATE/LRU/OSE					✓				✓						✓						✓						✓			
FAILURE RATE/LRU/RSE					✓				✓						✓						✓						✓			
FAILURE RATE/VAN		✓					✓		✓				✓											✓		✓				
FAILURE RATE/TRANSPORTER		✓					✓		✓				✓											✓		✓				
FAILURE RATE/HELICOPTER		✓					✓		✓				✓											✓		✓				
TOTAL NUMBER OF AVE FAILURE					✓				✓						✓						✓						✓			
TOTAL NUMBER OF AVE NO LAUNCH FAILURE					✓				✓						✓						✓						✓			
TOTAL NUMBER OF OSE FAILURE					✓				✓						✓						✓						✓			
TOTAL NUMBER OF OSE NO LAUNCH FAILURE					✓				✓						✓						✓						✓			
TOTAL NUMBER OF RSE FAILURE					✓				✓						✓						✓						✓			
TOTAL NUMBER OF VAN FAILURE		✓					✓						✓											✓		✓				
TOTAL NUMBER OF TRANSPORTER FAILURE		✓					✓						✓											✓		✓				
TOTAL NUMBER OF HELICOPTER FAILURE		✓					✓						✓											✓		✓				
SPEED OF VAN		✓					✓			✓					✓		✓						✓	✓		✓			✓	
SPEED OF TRANSPORTER		✓					✓			✓					✓		✓						✓	✓		✓			✓	
SPEED OF HELICOPTER		✓					✓			✓					✓		✓						✓	✓		✓			✓	
NUMBER RSE REPAIR TEAM	✓					✓						✓						✓		✓										
SIZE OF RSE REPAIR TEAM	✓					✓						✓						✓		✓										
SIZE OF AVE R/R TEAM	✓					✓						✓						✓												
SECURITY REACTION TIME				✓						✓							✓						✓						✓	
NUMBER HRS/DAY/MAN																✓				✓										
NUMBER DAYS/BASE PERIOD																✓				✓						✓				
NUMBER HRS/DAY/VAN																✓										✓				
NUMBER HRS/DAY/TRANSPORTER																✓										✓				
COST/VAN																✓														
COST/TRANSPORTER																✓														
COST/HELICOPTER																✓														
PERSONNEL COST/OSE R/R TEAM																✓														
PERSONNEL COST/AVE R/R TEAM																✓														
PERSONNEL COST/MULTIPLE SKILL TEAM																✓														
PERSONNEL COST/OSE MOVING TEAM																✓														
PERSONNEL COST/AVE MOVING TEAM																✓														
PERSONNEL COST/INSPECTION TEAM																✓														
PERSONNEL COST/C3-SECURITY REPAIR TEAM																✓														
PERSONNEL COST/RSE REPAIR TEAM																✓														

7.0 RECOMMENDED TRADE STUDIES

The studies listed in this section are identified in order to provide awareness only. These studies would be helpful to the planning and/or design of the FDD and related areas required to support the MX force and are not necessarily intended for inclusion in this study.

7.1 Maintenance

7.1.1 Definition of LRU

In defining the equipment components that constitute each LRU for a given maintenance stategy, components should be combined with approximately equal failure rates for the given LRU. This will minimize inventory requirements, pipeline costs, and reduce the number of maintenance discrepancies.

7.1.2 Force Availability vs. Dispatch Policies

Investigate the relationship and resulting conditions on force availability for various dispatch policies of maintenance teams.

7.1.3 Maintenance Team Composition

Identify the best mix of skill levels for a given maintenance plan to minimize missile down time while preserving force security and minimizing costs.

7.1.4 Integrated Logistic Support Studies

Examine the effect upon each ILS area for a given FDD candidate system.

7.1.5 Maintenance Costs (Also see Sec. 7.4)

Estimate the dollar costs associated with the alternate maintenance scenarios.

7.2 Missile Location

The following studies should be accomplished to provide support to MX development decisions:

7.2.1 Number of AMF

The number of AMF and their scope of activity should be analyzed for:

1. Installation costs
2. Number of PS per AMF
3. Distribution of Response times for maintenance
4. Force Availability
5. Impact on Dispatch rules, Number of personnel, skills, and documentation
6. Spares pipeline & inventory levels
7. Integrated Logistics Support Costs

7.3 OCC Functions

7.3.1 AOCC Configuration Study

Define the role of AOCC and its affects on EWO. Consider the level of OCC redundancy required for optimal control of missile maintenance and operations.

7.3.2 Operational Readiness requirements for OCC and AOCC

7.3.3 OCC/AOCC Logistics

Definition of ILS requirements for OCC and AOCC

7.3.4 OCC Information Flow

Define information flow requirements for OCC/AOCC functional areas (i.e., Maintenance Control, Security Control, etc.)

7.3.5 Maintenance Control Interfaces

Study of Maintenance Control Interface with other OCC functions.

7.3.6 OCC and ILS Interfaces

Study of the interfaces among the ILS areas, OCC, and the Maintenance Control of the Missile Force.

7.4 Cost Studies

7.4.1 Cost Models for ILS

Structure of a cost model for each element of ILS

7.4.2 Total ILS Costs vs. Number of AMF

Variation of ILS costs with an increase/decrease in number of AMF

7.4.3 Maintenance Costs of each candidate system

Identify cost of maintenance for each candidate system

7.4.4 Maintenance Costs vs. Number of AMF

Show the variation in maintenance costs for each different number of AMF

7.4.5 Cost vs. Force Availability

Show the cost variation for increasing force availability

7.4.6 SAMSO Cost Model Studies

Enhancement of SAMSO cost model; comparison of results of SAMSO single criterion cost model with a multiple Criteria analysis for FDD.

7.4.7 Total ILS costs vs. Number of AMF

Show how ILS cost will vary for different Maintenance Scenarios.

7.4.6 BMO Cost Model Studies -

1. Show how BMO cost model emphasizes MX system acquisition criteria.
2. Supplement cost model in the maintenance and ILS areas.

8. FOLLOW-ON ACTIVITIES

8.1 Adaptation to Changes in MX Concept

In the event of a change from the vertical PS concept, a restructuring of the analysis will occur and the scenarios developed will be reconsidered in their new concept.

8.2 Optimal FDD System Selection

The optimal FDD candidate system will be selected in the follow-on activity by using the design morphology as stated in the current study. Anticipated activities will include:

1. OCC/Site Maintenance Interface Studies
2. Completion of Candidate Screening
3. Estimation of Candidate System Parameters
4. Computerized Evaluation of Candidate Systems
5. Parameter Sensitivity Study
6. Identification of Optimal Candidate System

8.3 OCC Maintenance Control Analyses

An increased level of effort will be expended on improved clarity of the maintenance control function within the OCC. The operations-maintenance-C^3 interface is shown in Figure 18. Clarification of the shown interfaces will be accomplished through the following studies:

1. Definition and clarification of the Maintenance Control Information Flow
2. Clarification of Maintenance Control interfaces
3. FDD Requirements for OCC
4. Studies of the support/logistics problem as required

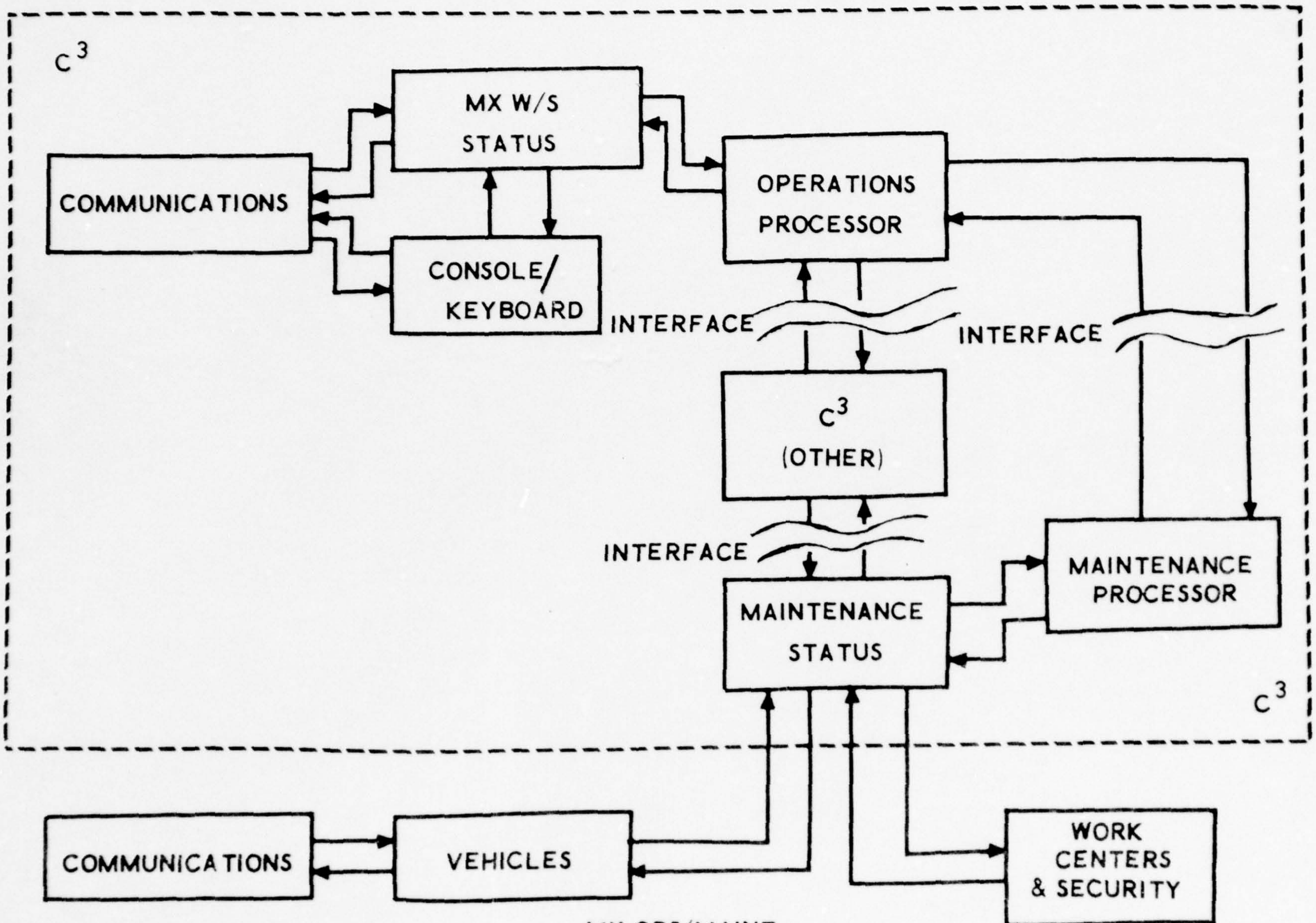


FIGURE 18:- MX OPS/MAINT INTERFACE AREAS

9.0 CONCLUSIONS

9.1 The Design Morphology

Application of the design morphology appears to be effective. In approaching the unstructured problem of the FDD the difficulties of problem definition were greatly simplified by the requirements of the morphology. Responding to the decision structure provided a more pointed direction to proceed in the determination of proper information from which to respond to the required decisions exercised to this point in the research. Hence the input-output results, the synthesis of the three scenarios and the emerging 180 candidate systems, the definition of the criteria and their respective relative weights, and the identification of submodels and parameters all were accomplished in a straight-forward manner so that verification of the usefulness of the morphology has been demonstrated to the level completed during the study.

9.2 Human Resources and Logistics Factors Influence

The design morphology provided a useful vehicle for clearly defining the functions or tasks that are required to meet the needs specified for the FDD. Hence the role of the human resource and logistics in FDD becomes clear when scenarios are developed from which decisions will be made concerning the particular manner in which the FDD functions will be accomplished. When the 180 candidate systems are evaluated through the use of the criterion function (which will be developed), the application of the human resource in the successful accomplishment of tasks will be automatically defined. Since the criterion function will enable the ranking of candidate systems, the proper mix of man-machine activity will emerge by choosing the highest ranked system, thus a defacto choice of the best mix of man-machine functions.

9.3 MX System Knowledge

It was recognized early that the final concept for deployment of the MX was not defined, and probably would not be defined during the accomplishment of this research. Hence the University of Houston team proceeded with the morphology application and considered the latest thinking at that time. Consequently all decisions made were to permit progress through the morphology, but were accomplished with the notion that any change in the MX concept would minimally influence the progress of the research. Hence for FY80, with several minor exceptions, all work accomplished will apply to the latest executive decisions on the MX configuration. Further, the research team at the University of Houston has bootstrapped its capability to be productive and will be capable of early implementation of any MX concept decided upon. Hence FDD development can be expected to keep pace with its defined schedule.

9.4 FDD Scenarios

The MX maintenance scenarios examined in this research require additional development. The conclusions suggested by Figure 6 were achieved through subjective comparisons of each area of Integrated Logistics Support. The activities required for formal optimization are planned for FY80 and will provide an analytic model from which to compare scenario performance for the consistent set of weighted criteria already defined. However, it currently appears from subjective study that having SMSB accomplish maintenance Control Functions under the cognizance of OCC will provide effective logistics support.

Further having the SMSB function physically close to the OCC will probably combine the advantages of most effective management control over the FDD activity with the efficient logistics support provided by having SMSB control the activities of maintenance analysis and dispatch.

9.5 Formal Optimization of FDD

This FY79 activity has shown that the development of a formal mathematical statement that includes the criteria agreed upon for FDD is feasible. Figure 17 shows the design parameters defined (86 of them), and which parameters are expected to relate to each submodel and/or criterion, and which submodels relate to each criterion. By developing these analytical relationships a formal, closed form, analytical expression can be developed that expresses each criterion in terms of the measurable parameters from each candidate system. So that while development of the six-criterion function in terms of 86 variables is complex, it is well within the analysts' abilities (and will be demonstrated in FY80).

To rank the 180 candidate systems, estimates of each input variables of Figure 17 must be provided for each candidate system. This will be accomplished and the resulting figure-of-merit of the criterion function will be ranked, the optimal candidate system being number one.

APPENDIX A

MAINTENANCE STUDY

The maintenance analysis has been occupied with the development of a Monte-Carlo simulation model of the maintenance system for a vertical launch MX missile system. The model has been designed with as much flexibility as possible to permit the analysis of a variety of maintenance strategies and scenarios. The program is modular and allows for additions and modifications with a minimum of disturbance to the previously written code. In order to allow the system to be as portable and machine independent as possible all programming has been done in standard FORTRAN. Testing of the program at each step is now done both on IBM and Honeywell computing systems to insure that portability is maintained.

Figure A-1 shows a hypothetical MX maintenance scenario that will be used to demonstrate the model. In this situation a single AMF is required to service six missile sectors. The x, y coordinate (in miles) of the AMF and the sectors are shown. Each missile sector has ten launching sites, but only one missile is kept per sector. The mean time between failure for the OSE and the AVE for each missile are inputs and shown in Table A-1.

Table A-1

Missile Failure Information

	MTBF(HOURS)	% Failures Causing no Launch
OSE	250.0	28.0
AVE	400.0	35.0

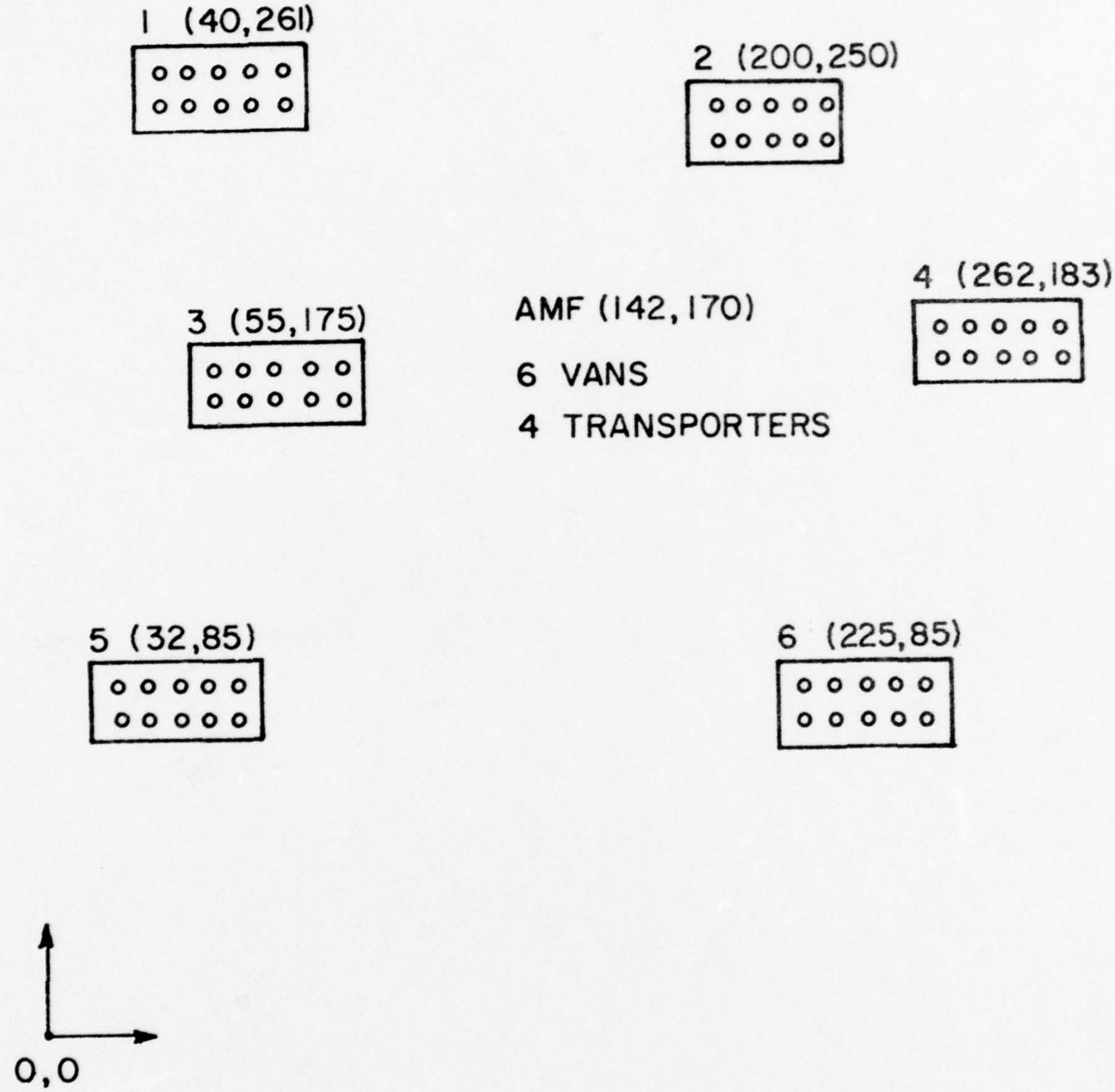


Figure A-1 Hypothetical MX Maintenance Scenarios

Table A-1 also shows (as input) that 28% of the failures in the OSE will cause the missile to be unlaunchable, and 35% of the failure in the AVE will also cause an unlaunchable situation. These percentages are inputs to the analysis. In the example scenario, the AMF will respond to no-launch and still-launchable-failures in the same manner and it has 6 van type vehicles for servicing OSE failures, and four large transporter for AVE failures. Travel speed for a van is 30 mph and 17 mph for a transporter. When the AMF responds to a failure the proper vehicle (van or transporter) is dispatched to the sector in a straight line distance. An option in the system can cause travel movement to be rectilinear. In order to preserve location uncertainty (PLU) each site in the sector is visited in a random sequence and all ten sites are visited in a sector for each failure. The time spent at each site will be a random value from a probability distribution and the time for an OSE repair (actual or simulated) will be from a normal distribution with a mean of 60 minutes and a variance of 9 minutes. For the AVE the time will be from a normal distribution with a mean of 180 minutes and a variance of 15 minutes. It is emphasized that these times will be spent at each site whether or not the site contains a missile. Travel time between sites is a constant half hour for a van and an hour for a transporter. Also, the modeler has full control over travel rates, repair times, site locations, mean time between failures, and all other parameters that are discussed in this example.

In the example, the dispatch strategy that will be employed is as follows. Repair vehicles will be dispatched at 24 hour intervals, and once a vehicle arrives at the sector and begins the sequence of site visits, it will continue the visits until all sites are completed. Only after all sites are visited will the vehicle return to the AMF. If no vehicles are available to service a failure at a dispatch time, the failure will remain unserviced until the next dispatch time. As will be explained later, the modeler has a variety of dispatch strategies available for examination.

Figure A-2 shows the output when this model was run. The first portion is an echo of the model input. The simulation program selects randomly the site containing the missile for each sector. These locations are given in the output in the right hand column of the sector information list. After the simulation echos the input information the simulation results are displayed. These results are shown in the remainder of Figure A-2.

The model will automatically print a report on the status of each missile every 24 hours. From t = 0 until t = 24 there were no missile failures and this is indicated on the output report at t = 24 (See figure A-Z). There were also no failures during the period from t = 24 until t = 48. At t = 49.554 hours there was a failure in the OSE of region 5. The failure code was 10 which indicates that the missile is still launchable. A failure code of 11 signals an OSE failure and the missile is unlaunchable. For the AVE failures a code of 20 means still launchable and a code of 21 means unlaunchable. The output shows additional failures in region 1 at 52.193 and region 2 at 57.583. The report at t = 72.00 shows the status of all sectors. Sectors that are in the status "*down" are still launchable. A status of "** down" means unlaunchable. Following on with the output, it can be seen that at t = 76.556 a crew arrives at region 1. This crew was dispatched at t = 7 as specified by the maintenance strategy. It will then visit all ten sites in a random sequence generated by the program. These visits can be traced by examining the output. At t = 88. the actual missile is visited, and it is put in a ready condition at t = 89.178. The report at t = 96 shows all missiles ready.

The output shown is the most detailed obtainable. The user can suppress any of the output that he does not need, and in most applications only

SIMULATION OF A MISSILE SITE MAINTENANCE OPERATIONS SYSTEM

MODEL IS SIMULATED FOR: 1000.000 HOURS

MODEL DESCRIPTIONS

REGION INFORMATIONS

NUMBER OF REGIONS= 6

REGION	SITE LOCATIONS		NO. OF SITES	
1	40.000	261.000	10	2
2	200.000	250.000	10	1
3	55.000	175.000	10	7
4	262.000	183.000	10	8
5	32.000	85.000	10	4
6	225.000	85.000	10	5

	MEAN TIME BETWEEN FAILURES	PERCENT OF *NO LAUNCH*
OSE	250.0000	0.2800
AVE	400.0000	0.3500

AMF INFORMATIONS:

NUMBER OF MAINTENANCE FACILITIES= 1

	FACILITY LOCATION		RESOURCES	
	X	Y	VANS	TRANSPORTERS
1	142.000	170.000	6	4

VAN SPEED = 30.000 MPH
TRANSPORTERS SPEED = 17.000 MPH

*** STRATEGY ONE :

- CREW DISPATCHES AT THE BEGINNING OF THE PERIOD ALL FAILURES OCCURRED IN THE LAST PERIOD.

- CREW IS ALLOWED TO WORK THE ENTIRE PERIOD.

REPORT AT TIME = 24.000

REGION	OSE	AVE
1	READY	READY
2	READY	READY
3	READY	READY
4	READY	READY
5	READY	READY
6	READY	READY

FIGURE A-2

```
REPORT AT TIME =          48.000
     REGION           OSE              AVE
         1            READY            READY
         2            READY            READY
         3            READY            READY
         4            READY            READY
         5            READY            READY
         6            READY            READY
TIME =          49.554
OSE FAIL IN REGION  5    FAIL CODE 10
TIME =          52.193
OSE FAIL IN REGION  1    FAIL CODE 10
TIME =          57.583
AVE FAIL IN REGION  2    FAIL CODE 20
  REPORT AT TIME = 72.000
     REGION           OSE              AVE
         1            * DOWN           READY
         2            READY            * DOWN
         3            READY            READY
         4            READY            READY
         5            * DOWN           READY
         6            READY            READY
AT TIME = 76.556
CREW ARRIVES AT REGION    1     FROM AMF  1
NUMBER OF SITE TO VISIT  10
AT TIME = 76.634
CREW ARRIVES AT REGION    5     FROM AMF  1
NUMBER OF SITES TO VISIT 10
AT TIME = 77.056
CREW ARRIVES AT SITE           6 OF REGION         1
ACTUAL MISSILE IS =      2
AT TIME = 77.134
CREW ARRIVES AT SITE           6 OF REGION         5
ACTUAL MISSILE IS =      4
AT TIME = 77.813
CREW ARRIVES AT REGION    2 FROM AMF          1
NUMBER OF SITES TO VISIT 10
AT TIME = 78.280
CREW ARRIVES AT SITE           8 OF REGION         1
ACTUAL MISSILE IS = 2
AT TIME = 78.591
CREW ARRIVES AT SITE           9 OF REGION         5
ACTUAL MISSILE IS = 4
AT TIME = 78.813
CREW ARRIVES AT SITE           1 OF REGION         2
ACTUAL MISSILE IS = 1
AT TIME = 80.595
CREW ARRIVES AT SITE           5 OF REGION         1
ACTUAL MISSILE IS = 2
AT TIME = 81.152
CREW ARRIVES AT SITE           4 OF REGION         5
ACTUAL MISSILE IS = 4
```

FIGURE A-2 (continued)

```
AT TIME = 82.019 AVE OF MISSILE AT REGION  2BACK TO READY STATE
AT TIME = 82.134 OSE OF MISSILE AT REGION  5BACK TO READY STATE
AT TIME = 83.019
CREW ARRIVES AT SITE           5 OF REGION          2
ACTUAL MISSILE IS = 1
AT TIME = 83.968
CREW ARRIVES AT SITE           3 OF REGION          1
ACTUAL MISSILES IS =      2
AT TIME = 84.695
CREW ARRIVES AT SITE           3 OF REGION          5
ACTUAL MISSILE IS = 4
AT TIME = 88.219
CREW ARRIVES AT SITE           2 OF REGION          1
ACTUAL MISSILE IS = 2
AT TIME =      89.122
CREW ARRIVES AT SITE           5 OF REGION          5
ACTUAL MISSILE IS = 4
AT TIME = 89.178 OSE OF MISSLE AT REGION  1BACK TO READY STATE
AT TIME = 90.029
CREW ARRIVES AT SITE      6 OF REGION          2
ACTUAL MISSILE IS = 1
AT TIME =      93.430
CREW ARRIVES AT SITE      10 OF REGION         1
ACTUAL MISSILE IS =       2
AT TIME = 94.466
CREW ARRIVES AT SITE      7 OF REGION          5
ACTUAL MISSILE IS = 4
REPORT AT TIME =     96.000
     REGION         OSE       AVE
          1         READY     READY
          2         READY     READY
          3         READY     READY
          4         READY     READY
          5         READY     READY
          6         READY     READY
TIME =     99.496
AVE FAIL IN REGION        5     FAIL CODE 20




THE AVAILABILITY OF MISSILE AT REGION 1 IS        0.593
THE AVAILABILITY OF MISSILE AT REGION 2 IS        0.589
THE AVAILABILITY OF MISSILE AT REGION 3 IS        0.887
THE AVAILABILITY OF MISSILE AT REGION 4 IS        0.772
THE AVAILABILITY OF MISSILE AT REGION 5 IS        0.564
THE AVAILABILITY OF MISSILE AT REGION 6 IS        0.455
```

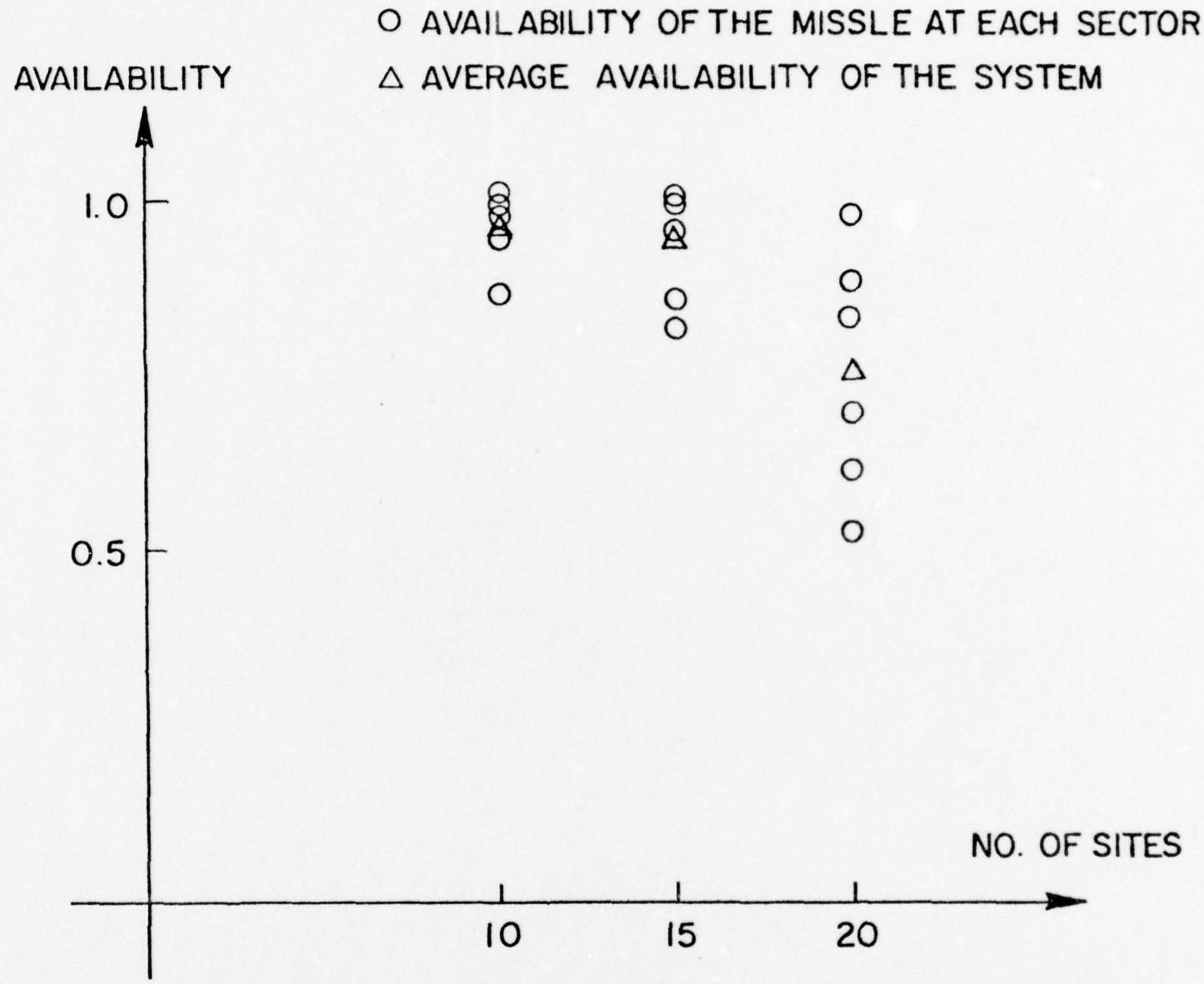
FIGURE A-2 (Continued)

the summary table at the end of the simulation will be requested. This shows the percent of time during the simulation that each missile was launchable. Figure A-3 shows the degradation of force availability as the number of sites is increased in each sector.

Two other strategies are available to the modeler at this time. One of them allows dispatch from the AMF as soon as the failure is detected, and the maintenance at the sector continue until all sites are visited. The other available strategy dispatches from the AMF at twenty-four hour intervals, but restricts the period that the repair crew can work at the site. The work period is specified by the modeler. This strategy requires transporters servicing AVE's to be back at the AMF at the end of this period. Vans servicing the OSE's must leave the sector at the end of the period. For example, suppose the work period was specified to be ten hours' and a van and a transporter were dispatched at t = 48. The transporter must be back at the AMF at t = 58 and the van must stop work at the sector at t = 58. The van would then return to the AMF. At the next dispatch time, at t = 72, the van and transporter would travel again to the sector they were servicing and pick up the sequence of site visits. All three of the strategies that are now included in the model have been proposed as possibilities to be investigated. A modeler may investigate the use of any of them and see the effect they have on missile availability and equipment utilization.

Activities for the coming year will be as follows:

1. Adapt the model to any changes in MX concepts.
2. Use the model to investigate the effect of varying FDD system parameters for the scenarios identified. For example, in the hypothetical scenario of this report, ten sites were included in a sector. What would be the effect



AVAILABILITY VARIES WITH NO. OF SITES IN THE SYSTEM
(STRATEGY ONE)

FIGURE A-3

of including more or less sites on missile availability? What would be the effect of changing the number of service vehicles, or the number of AMF's, or the location of the AMF? Many parameters of this type require investigation.

3. Expand the model to include other maintenance strategies that may be suggested. The model is very modular and allows for convenient modification.
4. Modify the model to include vehicle utilization. Presently it gives no measure of vehicle utilization which must be included to allow more reasonable assessments of alternatives.
5. Include additional modifications to respond to the needs of maintenance control requirements for more effective OCC operations.

APPENDIX B

FACILITIES LOCATION ANALYSIS

Introduction

Within the general scope of the MX Location Analysis, the problem can be addressed for the location decisions of:

1. Support Base (SMSB)
2. Primary Support Area (PSA)
3. Alert Maintenance Facility (AMF)
4. Security Alert Facility (SAF)
5. Launch Sites (Protective Structures, PS)

The scope of this study is limited to the location analysis of the AMF in the support of a given maintenance concept. Hence, some or all of the remainder of the facilities (viz: 1, 2, 4, and 5) described above will be treated as either given or not in the general design of the this program. For instance, the primary support areas may be included at the existing support bases; the geometry of the protective structures may already be given and the locations of the security alert areas may already be pre-determined. However, even within this restricted scope, the location decisions pertaining to the AMF is a critical and complex problem and involves seeking answers to the following:

1. How many AMF should be utilized?
2. Where should these AMF be located?
3. What should be the size (capacity to satisfy the maintenance requirements) of the these AMF?
4. What should be the territorial allocation of these AMF with respect to the protective structures? i.e. what launch sites will be maintained/ serviced by which AMF?

The answers to these questions will clearly provide an input to the support of the Fault Detection and Dispatch (FDD) system.

Because of this interface, the "Dispatching Rules" (the rules by which the maintenance team at the AMF will be dispatched to the launch site upon fault detection) will be strongly dependent upon the location decisions of AMF. Accordingly, several dispatching rules including the baseline concept and randomized dispatch rules will be developed and used in the location analysis. Additional requirements and/or considerations like PLU, SALT verification, and costs will be included in the final location decision models.

The next section provides a brief survey of the vast literature that exists in the location area, this includes theoretical and practical studies dealing with the location of facilities in both the public and the private sector (e.g.: plants, warehouses, fire stations, medical centers, post offices, etc.). The analysis will provide the maintenance formulations of the different location problems and the proposed solution methods; this will then provide a basis for formulating the AMF location problem with the appropriate objectives and constraints and procedures for solving it. A computer program is shown immediately following in Appendix B.

Literature on Location Analysis

Locational analysis has been recognized to have applications in many real life contexts in both the private and the public sectors:—for example, location of plants, depots and warehouses, hospitals, fire stations and emergency supply centers, post offices, an intermediate station in a solid waste collection and disposal system, etc. The last fifteen years have seen rapid advances in its solution methods and applications. At the root of this expansion in capability are new methods of analysis including optimization techniques and mathematical models which have vastly expanded the spectrum of alternative that the analyst can examine.

These methods of analysis are no panacea for pouring out "optimal" solutions since the real world with its immense complexity tends to defy exact analogs. The results of analyzing these models may be optimal in reference to the models, but they are not necessarily the best results for the real world. Rather, the results are regarded as an aid to the analysts' intuition and not as a replacement for it. The greatest aid the models provide is a better understanding of the sensitivity of solutions to changes in parameters, constraints or objectives. It remains for the analyst to ascertain from among the "good" solutions those which he feels meet the needs and demands of his problem most closely.

The similarities and differences in the location problems and associated models in the public and private sectors are discussed first. They are both alike in that they share the objective of maximizing some measure of utility to the owners while at the same time satisfying constraints on demands and other conditions. In the narrow sense, they differ in the way that these objectives and constraints are formulated. However, in the broad sense, they differ because the ownership is different. The decisions on private sector location involve a host of issues including only some of a non-economic nature, but a reasonably accurate statement of the objective is the minimization of cost or a maximization of profit to the private owners. On the other hand, military facility decisions are made in response to a different set of "owners" and the objective here is to maximize a benefit or to minimize a cost which is not accurately quantifiable in dollar terms.

Location decisions for the AMF involve all the private sector problem plus the additional dilemma that goals, objectives and constraints are usually more difficult to quantify. There are two ways in which the AMF location problems can be treated: One is the objective function method where an attempt is made to identify and quantify factors affecting the social cost. This is exceedingly difficult to do and as such very few studies can be found which have taken this approach. The second approach of analysis is to utilize some surrogate or substitute measure of utility. The intent here is not to be able to define solutions, but to gain more information about the system under analysis. For example, one surrogate that can be used in the location decision of AMF is the average distance or time involved by those using the facilities. The smaller this quantity, the more accessible it is to its users. Another surrogate for utility could be the maximum distance or time between any facility and the areas which it is intended to serve.

These surrogates can then be optimized subject to constraints on investment and this constraint may be in the form of an explicit limitation on dollar expenditures (fixed construction costs and annual operating costs) or could be in the form of a specified number of facilities which can be established. The latter may be set due to political considerations and may or may not reflect budgetary restrictions. Having arrived at first solutions using such objectives and constraints, one can begin to evaluate sensitivity of the solutions to parameter estimates. If these parameters do not greatly influence the solution, the next stage of analysis is to examine the trade offs between investment and utility. The final choice might be made from among the alternatives generated at different levels of funding.

Morphology of Location Systems

Problems in location analysis can be classified into two major categories:

A. Location on a Plane (continuous)

B. Location on a Network (discrete)

A. Location on a plane is characterized by:

1) An infinite solution space; i.e., the facilities may be located anywhere on the plane and are neither confined to the nodes of the network nor to the points on the links between these nodes. The obvious drawback is -- what if the solution suggests the location of the facility at an infeasible point (downtown Las Vegas)?

2) Distance measurement according to a particular metric e.g.: the Euclidian metric where

$$d^2_{ij} = (x_i - x_j)^2 + (y_i - y_j)^2 \quad (1)$$

where:

d_{ij} = distance between points i and j

x_i, y_i = coordinates in the rectangular system of the ith point

B. Location on a network is characterized by:

1) A solutions space consisting of pre-selected discret points on the network, the obvious drawback here is the possible exclusion of good points in the pre-selection.

2) Distance and/or time measurement along the network. Here d_{ij} = the length (time) of the shortest path from node i to node j

Historically, location analysis began with Alfred Welser who considered the location of a plane of a factory between two resources and a single market. Beginning with the formulation of Cooper and Kuhn and Kuenne, interest in location analysis quickened. However, somewhat more attention has been devoted to problems of locating facilities on a network; these take the form of either public or private sector problems. In the private sector, for example, the warehouse or plant location problem has the following general characteristics.

Given a number of demand areas (customers) for a certain product(s) or service(s), and a number of pre-selected candidate sites where facilities can be established to satisfy these demands, determine where the facilities should be established and which demand areas are to be served by a given facility. The objective is that the sum of the transportation costs (to and from the facilities) and the fixed and operation costs of the facilities are to be minimized.

The flow of products or services may be toward the facility (such as the OCC) or from the facility to the demand area (such as Transportation Control). Another aspect of this discrete location problem is that the existing facilities can be included in the set of candidate sites and expansion or contraction of existing facilities can also be easily incorporated as part of the location problem.

The general mathematical formulation of the aforementioned location problem on a network for a single product or service given by:

$$\text{Minimize} \quad Z = \sum_i \sum_j c_{ij}(x_{ij}) + \sum_i F_i(y_i); \tag{2}$$

$$\text{Subject to:} \quad \sum_i x_{ij} = D_j \text{ for all } j \tag{3}$$

$$\sum_j x_{ij} \leq s_i y_i \text{ for all } i \tag{4}$$

$$x_{ij} \geq 0 \text{ for all } i \text{ and } j$$

$$y_i \geq 0 \text{ for all } i \text{ and } j$$

where:

x_{ij} = amount of products or services supplied from location i to demand area j

y_i = usually a 0,1 variable indicating the absence or presence of the facility at candidate location i

$c_{ij}(x_{ij})$ = cost of supplying products or services from i to j

$F_i(y_i)$ = cost of establishing and operating the facility at location i

D_j = the demand at area j

n = number of demand area (j = 1, 2, ..., n)

m = number of preselected sites (i = 1, 2, ..., m)

The objective function, Equation 2, consists of the total costs including both fixed and variable. Constraints, Equation 3, are to satisfy the demand area requirements for service (as product); constraints, Equation 4, impose limitations on the capacity that a candidate facility at location i can provide which therefore cannot be exceeded.

Usually the function $F_i(y_i)$ is non-linear as it exhibits a large fixed investment for land, foundation, physical buildings, utilities, etc., along with the annual fixed costs of maintaining and operating the facilities. Once the facility is established, the marginal cost may decrease due to economics of scale. Thus, the problem is not amenable to straight forward linear programming.

One simple non-linear form that the function $F_i(y_i)$ can take is:

$$F_i(y_i) = f_i = v_i(\Sigma\, x_{ij}) \quad \text{if } y_i = 1 \qquad (5)$$

The following shows the forms of Eq. 5:

$$F_i(y_i) = f_i + v_i(\Sigma\, x_{ij})$$

Thus $F_i(y_i)$ consists of a fixed change that is independent of the service and a linear cost depending on the service provided. Notice that once the y_i vector is specified (i.e. it is decided at which of the n candidate locations the facilities will be established). The remainder of the problem given by (1) - (5) is a straight forward linear program. However, there are a total of 2^n possible y_i vectors i.e. configuration of facilities from which to choose the best configuration. The complexity of the problem and its relationship to n, the number of candidate locations is illustrated by the following table which provides the values of 2^n for different n.

n: # of candidate locations	2^n = # of possible configurations
2	4
4	16
8	256
10	1,024
15	32,768
30	2,147,483,648

FIGURE B-1: Number of candidate Location vs. Number of Possible Configurations

The complexity of the problem is slightly diminished (but not by much) when one prespecifies the number of facilities that will be employed from among the total candidates. For example, in the AMF location problem, suppose the candidate locations chosen are 25 and it has been established to have 5 AMF. In this case, the problem is simply to identify where the five AMF will be established among the 25 locations. In such a case, the number of configurations to be evaluated will not be 2^{25} (33,554,432), but only ${}_{25}C_5$ or 53,130, still a fairly large number.

Problem II:

The mathematical formulation of the location problem in the above case will be given by Equations 2, 3, 4:

Minimize $Z = \Sigma_{ij} C_{ij}(x_{ij}) + \Sigma_i F_i y_i$

Subject to:

$$\Sigma_i x_{ij} = D_j \qquad \text{for all } j$$

$$\Sigma_j x_{ij} \quad S_i y_i \qquad \text{for all } i$$

as well as:

$$\Sigma_i y_i = p \tag{6}$$

$$x_{ij} \geq 0$$

$$y_i = 0,\ 1$$

where p = number of facilities to be established.

Another variation to the above formulation takes place when the fixed costs of the AMF may be the same regardless of the general location at which they are established. In such a situation the fixed costs are committed by the established budget and should be considered in the objective function. The resulting mathematical formulcation would be then be:

Problem III:

Minimize $Z = \Sigma_{ij} C_{ij} x_{ij}$

Subject to:

$$\Sigma_i x_{ij} = D_j \qquad \text{for all } j$$

$$\Sigma_j x_{ij} \leq S_i y_i \qquad \text{for all } i$$

$$\Sigma_i y_i = p$$

$$1 \ p \ x_{ij} \geq 0 \quad \text{for all } i$$

$$y_i =$$

$$0 \text{ otherwise}$$

$$x_{ij} \geq 0 \qquad \text{for all } i \text{ and } j$$

It is easy to see that Problem II and III can be solved parametrically on p, the preselected number of facilities.

Solution Approaches

As stated earlier, the simplest approach to solving the location problem would be by a complete enumeration of all the configurations of the candidate locations. After each of these configurations is evaluated, the one most desirable according to the stated objective can be ascertained. This method, in addition to being simple, easily permits investigation of the configurations according to multiple criteria. Also, since the approach can easily provide a rank-order of the different configurations, the analyst is not limited to only one solution and can further analyze the effects of the 2nd, 3rd, and other sequential best solutions on the total system. This feature is particularly important when there are several attractive configurations available.

The major drawback of the complete enumeration approach is that the total number of configurations (see Figure B-1) increases exponentially with the number of potential sites. This makes the approach expensive and computationally infeasible even for a modest number of candidate locations. Because of this several implicit enumeration and heuristic approaches have been developed. Prominent among them are the branch and bound methods of Efroymson and Ray, Spielberg, Khumawala, Akine and Khumawala, Ellwein and Gray, Geoffrion and Graves, and Erlenkottis. Several very good heuristics have also been derived; notable among these are by Kuehn and Hamburger, Feldman et al., Khumawala, Khumawala and Kelly and others.

The implicit enumeration method allows for the elimination of several non-promising configurations and restricts to the explicit evaluation to only a few very promising configurations. This makes the approach feasible and computationally efficient. However, as the number of candidate locations in the problem increases, the implicit enumeration methods run into difficulty in arriving at the guaranteed best solution. Thus, one resorts to the use of heuristics and heuristic features in the implicit enumeration methods.

Computer Program

As described earlier, the AMF location problems can be formulated in one or more of the facility location problem formulations given in earlier sections. The computer code listing attached solves the following specific facility location problem.

$$
\begin{array}{lll}
\text{Minimize} & \Sigma_{ij}\, C_{ij}\, x_{ij} + \Sigma_i\, F_i\, y_i & \\
\text{Subject} & \Sigma_i\, x_{ij} = 1 & \text{for all } j = 1, 2, \ldots m \\
 & 0 \le x_{ij} \le y_i & \text{for all } i = 1, 2, \ldots n \\
 & & \qquad\quad j = 1, 2, \ldots m \\
 & y_i = 0, 1 \text{ (integer)} & \text{for all } i = 1, 2, \ldots n
\end{array}
$$

(The variables are as defined earlier with the modification that here c_{ij} is the cost of providing total required service at the j^{th} site from the i^{th} potential (AMF) location; hence s_{ij} is in proportion rather than in absolute units).

This computer program is extremely flexible since it can provide:

a) The "optimal" solution using the branch and bound method with several options of both branch and node selection rules (see Khumawala, Management Science, August, 1972)

b) Very "good" approximate solutions using one of eight heuristic rules (see Khumawala, Naval Research Logistics Quarterly, 73, 74).

The program is also considerably flexible as it can allow for a modest number of potential locations (for AMF's) and a very large number of launch sites by simply changing the dimension statements appropriately. Similarly, the output of the program can also be easily modified to provide a variety of information.

```
* MODLST 5188Q39,5208N12,5208N49,5318L56,5318N46,5318R18,5318U31
* MODLST 5318U51,6018K14,6028R26

      LOGICAL ZFEAS,KZ,K1,K2,ZY
      INTEGER UBD,XLBD,Z
      COMMON // MINC(60),
     <  MDEL(99,60),MDELS(99,35),MEGAS(99,35),Y(99,35),
     <  IFC(35),IVC(35,60),
     <  KODE(99),NBRCH(99),NFREE(99),LN(99,35),
     <  IDEL(99,60),ILN(35),KY(35),Z(99),
     < KZ(99,35),K1(99,35),K2(99,35),ZY(35)
 786  FORMAT(25X,16I6)
 162  FORMAT(///)
200   CONTINUE
      LCN=99999
      LLN=999999999
      READ(5,510,END=5800)NW,NC,NHR,MWS,MNS,UBD,NSAME
 510  FORMAT(V)
      IF(UBD.EQ.0)UBD=LLN
      WRITE(3,149)
 149  FORMAT('1',30X,'PROGRAM SPLP OUTPUT')
      WRITE(3,162)
      WRITE(3,150)NW
 150  FORMAT(25X, ' NUMBER OF AMF"S  =',I10)
      WRITE(3,151)NC
 151  FORMAT(25X, ' NUMBER OF PROTECTIVE STRUCTURES  =',I10)
      WRITE(3,152)NHR
 152  FORMAT(25X, ' EXACT OR HEURISTIC   =',I10)
      WRITE(3,153)MWS
 153  FORMAT(25X, ' BRANCH SEL HEURISTIC =',I10)
      WRITE(3,154)MNS
 154  FORMAT(25X, ' NODE SELECTION RULE  =',I10)
      WRITE(3,155)UBD
 155  FORMAT(25X, ' INITIAL UPPER BOUND  =',I10)
      IF(NSAME.EQ.0)GOTO 7860
      WRITE(3,162)
      WRITE(3,165)
 165  FORMAT(30X,'USING OLD DATA')
      GO TO 7863
 7860 WRITE(3,162)
      WRITE(3,166)
 166  FORMAT(35X,'NEW PROBLEM')
      READ(5,510)(IFC(I),I=1,NW)
      WRITE(3,162)
      WRITE(3,156)
 156  FORMAT(25X, ' FIX AMF COSTS ARE ')
      WRITE(3,786)(IFC(I),I=1,NW)
      WRITE(3,162)
      WRITE(3,163)
 163  FORMAT(25X,' VARIABLE COSTS ARE ',/)
      DO 7861 I=1,NW
      READ(5,510)(IVC(I,J),J=1,NC)
      DO 7862 J=1,NC
      IF (IVC(I,J).EQ.0) IVC(I,J)=LCN
 7862 CONTINUE
```

```
      WRITE(3,786)(IVC(I,J),J=1,NC)
 7861 CONTINUE
 7863 CONTINUE
      ZFEAS=.TRUE.
      NFINAL=0
      NAVL=0
      NFIRST=0
      NKTR=0
      NKTR1=0
      XLBD=0
      MODE=1
      NODE=1
      NODE=1
      XLN=LLN
      NUBDN=NODE
      ITER=1
      NFREE(NODE)=0
      DO 250 IW=1,NW
      LN(NODE,IW)=0
      MEGAS(NODE,IW)=LLN
      DO 100 IC=1,NC
      IF (IVC(IW,IC).LT.LCN)LN(NODE,IW)=LN(NODE,IW)+1
      IF (IW.LT.2)IDEL(NODE,IC)=0
  100 CONTINUE
      ILN(IW)=LN(NODE,IW)
      KZ(NODE,IW)=.FALSE.
      K1(NODE,IW)=.FALSE.
      K2(NODE,IW)=.TRUE.
      NFREE(NODE)=NFREE(NODE)+1
  250 CONTINUE
      NLBDN=1
      GO TO 1100
  300 ITER=ITER+1
      IF (NHR.EQ.0) GO TO 350
      IF (MWS.LE.4) GO TO 1050
      GO TO 900
  350 IF (NLBDN.EQ.1) GO TO 400
      IF (NKTR.EQ.1.OR.NKTR1.EQ.1) GO TO 700
      IF (NAVL.GT.0) GO TO 500
  400 NODE=MODE+1
      MODE=NODE
      IF (MODE.LE.99) GO TO 550
      WRITE (3,450)
  450 FORMAT (//,25X,'99 CELLS EXCEEDED')
      STOP
  500 NODE=KODE(NAVL)
      NAVL=NAVL-1
  550 DO 600 IC=1,NC
      IDEL(NODE,IC)=IDEL(NLBDN,IC)
      MDEL(NODE,IC)=MDEL(NLBDN,IC)
  600 CONTINUE
      DO 650 IW=1,NW
      KZ(NODE,IW)=KZ(NLBDN,IW)
      K1(NODE,IW)=K1(NLBDN,IW)
      K2(NODE,IW)=K2(NLBDN,IW)
      LN(NODE,IW)=LN(NLBDN,IW)
```

```
      MDELS(NODE,IW)=MDELS(NLBDN,IW)
      MEGAS(NODE,IW)=MEGAS(NLBDN,IW)
  650 CONTINUE
      NFREE(NODE)=NFREE(NLBDN)
      GO TO 750
  700 NODE=NLBDN
  750 IF (NKTR.EQ.0) GO TO (850,1000),NKTR1
      GO TO (950,800),NKTR
  800 NKTR=NKTR-1
      GO TO 900
  850 NKTR1=NKTR1-1
  900 KZ(NODE,KKW)=.TRUE.
      NFREE(NODE)=NFREE(NODE)-1
      NBRCH(NODE)=0
      K2(NODE,KKW)=.FALSE.
      GO TO 1100
  950 NKTR=NKTR-1
      GO TO 1050
 1000 NKTR1=NKTR1-1
 1050 K1(NODE,KKW)=.TRUE.
      NFREE(NODE)=NFREE(NODE)-1
      NBRCH(NODE)=1
      K2(NODE,KKW)=.FALSE.
      GO TO 1650
 1100 KKK=0
      DO 1450 IC=1,NC
      KTR=0
      DO 1300 IW=1,NW
      IF (KZ(NODE,IW)) GO TO 1300
      IF (IVC(IW,IC).GE.LCN) GO TO 1300
      IF (K1(NODE,IW).AND.IDEL(NODE,IC).EQ.IW) GO TO 1450
      KTR=KTR+1
      IF (KTR.EQ.1) GO TO 1150
      IF (KTR.EQ.2) GO TO 1200
      IF (IVC(IW,IC).GE.MINC2) GO TO 1300
      GO TO 1200
 1150 MINC1=IVC(IW,IC)
      MW=IW
      GO TO 1300
 1200 MINC1=MIN0(MINC1,IVC(IW,IC))
      IF (MINC1.EQ.IVC(IW,IC)) GO TO 1250
      MINC2=IVC(IW,IC)
      GO TO 1300
 1250 MINC2=IVC(MW,IC)
      MW=IW
 1300 CONTINUE
      IF (KTR.EQ.0) GO TO 1400
      IDEL(NODE,IC)=MW
      IF (KTR.EQ.1) GO TO 1350
      MDEL(NODE,IC)=MINC2-MINC1
      GO TO 1450
 1350 IF (K1(NODE,MW)) GO TO 1450
      K1(NODE,MW)=.TRUE.
      NFREE(NODE)=NFREE(NODE)-1
      K2(NODE,MW)=.FALSE.
      KKK=KKK+1
```

```
      GO TO 1450
 1400 IF (NODE.NE.1) GO TO 4250
      ZFEAS=.FALSE.
      WRITE(3,1401)
 1401 FORMAT('0',24X,'INFEASIBLE SOLUTION.')
      STOP
 1450 CONTINUE
      IF(NFINAL.NE.0)GO TO 5555
      KTR=KKK
      DO 1600 IW=1,NW
      IF (.NOT.K2(NODE,IW)) GO TO 1600
      MDELS(NODE,IW)=-IFC(IW)
      DO 1500 IC=1,NC
      IF (IDEL(NODE,IC).NE.IW) GO TO 1500
      MDELS(NODE,IW)=MDELS(NODE,IW)+MDEL(NODE,IC)
 1500 CONTINUE
      IF (MDELS(NODE,IW)) 1600,1550,1550
 1550 KTR=KTR+1
      K1(NODE,IW)=.TRUE.
      NFREE(NODE)=NFREE(NODE)-1
      K2(NODE,IW)=.FALSE.
 1600 CONTINUE
      IF (KTR.EQ.0) GO TO 2350
      IF (NFREE(NODE).EQ.0) GO TO 2350
 1650 DO 1750 IW=1,NW
      IF (.NOT.K2(NODE,IW)) GO TO 1750
      LN(NODE,IW)=ILN(IW)
      DO 1700 IC=1,NC
      IF (IVC(IW,IC).GE.LCN) GO TO 1700
      MM=IDEL(NODE,IC)
      IF (.NOT.K1(NODE,MM)) GO TO 1700
      LN(NODE,IW)=LN(NODE,IW)-1
 1700 CONTINUE
 1750 CONTINUE
      KKTR=0
      DO 1800 IW=1,NW
      IF (LN(NODE,IW).GT.0) GO TO 1800
      KKTR=KKTR+1
      NFREE(NODE)=NFREE(NODE)-1
      KZ(NODE,IW)=.TRUE.
      K2(NODE,IW)=.FALSE.
 1800 CONTINUE
      IF (KKTR.EQ.0) GO TO 1850
      IF (NFREE(NODE).EQ.0) GO TO 2350
 1850 JW=1
 1900 IF (K1(NODE,JW)) GO TO 1950
      JW=JW+1
      GO TO 1900
 1950 DO 2000 IC=1,NC
 2000 MINC(IC)=IVC(JW,IC)
      JW=JW+1
      IF (JW.GT.NW) GO TO 2150
      DO 2100 IW=JW,NW
      IF (.NOT.K1(NODE,IW)) GO TO 2100
      DO 2050 IC=1,NC
 2050 MINC(IC)=MIN0(MINC(IC),IVC(IW,IC))
```

```
2100 CONTINUE
2150 KTR=KKTR
     DO 2300 IW=1,NW
     IF (.NOT.K2(NODE,IW)) GO TO 2300
     MEGAS(NODE,IW)=-IFC(IW)
     DO 2250 IC=1,NC
     IF (IVC(IW,IC).GE.LCN) GO TO 2250
     IF (MINC(IC).GE.LCN) GO TO 2200
     MEGAS(NODE,IW)=MEGAS(NODE,IW)+MAX0(0,MINC(IC)-IVC(IW,IC))
     GO TO 2250
2200 MEGAS(NODE,IW)=MEGAS(NODE,IW)+IVC(IW,IC)
2250 CONTINUE
     IF (MEGAS(NODE,IW).GT.0.) GO TO 2300
     KZ(NODE,IW)=.TRUE.
     NFREE(NODE)=NFREE(NODE)-1
     K2(NODE,IW)=.FALSE.
     KTR=KTR+1
2300 CONTINUE
     IF (KTR.EQ.0) GO TO 2350
     IF (NFREE(NODE).NE.0) GO TO 1100
2350 Z(NODE)=0
     IF (NHR.EQ.0) GO TO 2400
     IF (MWS.EQ.4.OR.MWS.EQ.8) GO TO 2400
     IF (NFREE(NODE).GT.0) GO TO 4450
2400 DO 2500 IW=1,NW
     IF (K1(NODE,IW)) GO TO 2450
     Y(NODE,IW)=0
     GO TO 2500
2450 Y(NODE,IW)=1
2500 CONTINUE
     DO 2900 IC=1,NC
     KW=IDEL(NODE,IC)
     IF (KZ(NODE,KW)) GO TO 2550
     IF (K1(NODE,KW)) GO TO 2850
     XJN=LN(NODE,KW)
     IF (MDEL(NODE,IC).GT.IFC(KW)/XJN) GO TO 2850
2550 JW=1
2600 IF (.NOT.KZ(NODE,JW).AND.IVC(JW,IC).LT.LCN) GO TO 2650
     JW=JW+1
     IF (JW.GT.NW) GO TO 4250
     GO TO 2600
2650 AA=IVC(JW,IC)
     XLN=LN(NODE,JW)
     IF (K2(NODE,JW))AA=AA+IFC(JW)/XLN
     KW=JW
     JW=JW+1
     IF (JW.GT.NW) GO TO 2850
     DO 2800 IW=JW,NW
     IF (KZ(NODE,IW).OR.IVC(IW,IC).GE.LCN) GO TO 2800
     BB=IVC(IW,IC)
     XLN=LN(NODE,IW)
     IF (K2(NODE,IW))BB=BB+IFC(IW)/XLN
     IF (AA.NE.BB) GO TO 2700
     IF (K1(NODE,IW)) GO TO 2750
     GO TO 2800
2700 IF (BB.LT.AA)AA=BB
```

```
      IF (AA.NE.BB) GO TO 2800
 2750 KW=IW
 2800 CONTINUE
 2850 XLN=LN(NODE,KW)
      IF (K1(NODE,KW)) GO TO 2900
      Y(NODE,KW)=1./XLN+Y(NODE,KW)
 2900 Z(NODE)=Z(NODE)+IVC(KW,IC)
      IF (NFREE(NODE).GT.0.AND.NHR.EQ.1) GO TO 4450
      KTR=0
      DO 3000 IW=1,NW
      IF (Y(NODE,IW).EQ.0) GO TO 2950
      Z(NODE)=Z(NODE)+IFC(IW)*Y(NODE,IW)
 2950 IF (Y(NODE,IW).EQ.0.OR.Y(NODE,IW).EQ.1) GO TO 3000
      KTR=KTR+1
 3000 CONTINUE
      IF (KTR)  3050,3050,4200
 3050 IF (NFIRST.EQ.1) GO TO 3100
      IF (NODE.NE.3) GO TO 3100
      NFIRST=1
      IF (MNS.NE.4) GO TO 3100
      MNS=2
      IF (NW.LT.49)MNS=3
 3100 IF (NODE.EQ.1) GO TO 5500
      IF (UBD.GT.Z(NODE)) GO TO 3150
      Z(NODE)=LLN
      NAVL=NAVL+1
      KODE(NAVL)=NODE
      IF (NKTR.NE.0.OR.NKTR1.NE.0) GO TO 300
      GO TO 3250
 3150 UBD=Z(NODE)
      IF (NUBDN.EQ.1) GO TO 3200
      NAVL=NAVL+1
      KODE(NAVL)=NUBDN
 3200 NUBDN=NODE
      Z(NODE)=LLN
      IF (NKTR.NE.0.OR.NKTR1.NE.0) GO TO 300
 3250 JW=1
 3300 JW=JW+1
      IF (Z(JW).LT.UBD) GO TO 3400
      IF (Z(JW).GE.LLN) GO TO 3350
      NAVL=NAVL+1
      KODE(NAVL)=JW
      Z(JW)=LLN
 3350 IF (JW-MODE)  3300,5550,5550
 3400 XLBD=Z(JW)
      NLBDN=JW
      IF (JW.EQ.MODE) GO TO 4150
C
C     MNS
      GO TO (3450,3600,3750,3800),MNS
 3450 JW=JW+1
      DO 3550 I=JW,MODE
      IF (Z(I).LT.UBD) GO TO 3500
      IF (Z(I).GE.LLN) GO TO 3550
      NAVL=NAVL+1
      KODE(NAVL)=I
```

```
      Z(I)=LLN
      GO TO 3550
 3500 IF (Z(NLBDN).LE.Z(I)) GO TO 3550
      XLBD=Z(I)
      NLBDN=I
 3550 CONTINUE
      GO TO 4150
 3600 JW=JW+1
      DO 3700 I=JW,MODE
      IF (Z(I).LT.UBD) GO TO 3650
      IF (Z(I).GE.LLN) GO TO 3700
      NAVL=NAVL+1
      KODE(NAVL)=I
      Z(I)=LLN
      GO TO 3700
 3650 IF (NFREE(NLBDN).LE.NFREE(I)) GO TO 3700
      XLBD=Z(I)
      NLBDN=I
 3700 CONTINUE
      GO TO 4150
 3750 IF (NAVL.EQ.0) GO TO 3600
      GO TO 3450
 3800 IF (MWS.GT.4) GO TO 4000
      IF (NBRCH(JW).EQ.1) GO TO 4150
      JW=JW+1
      DO 3900 I=JW,MODE
      IF (Z(I).LT.UBD) GO TO 3850
      IF (Z(I).GE.LLN) GO TO 3900
      NAVL=NAVL+1
      KODE(NAVL)=I
      Z(I)=LLN
      GO TO 3900
 3850 IF (NBRCH(I).EQ.1) GO TO 3950
 3900 CONTINUE
      GO TO 4150
 3950 XLBD=Z(I)
      NLBDN=I
      GO TO 4150
 4000 IF (NBRCH(JW).EQ.0) GO TO 4150
      JW=JW+1
      DO 4100 I=JW,MODE
      IF (Z(I).LT.UBD) GO TO 4050
      IF (Z(I).GE.LLN) GO TO 4100
      NAVL=NAVL+1
      KODE(NAVL)=I
      Z(I)=LLN
      GO TO 4100
 4050 IF (NBRCH(I).EQ.0) GO TO 3950
 4100 CONTINUE
C
 4150 IF (UBD.LE.XLBD) GO TO 5550
      Z(NLBDN)=LLN
      GO TO 4450
 4200 IF (NODE.NE.1) GO TO 4350
      XLBD=Z(NODE)
      NLBDN=NODE
```

```
      Z(NODE)=LLN
      GO TO 4450
 4250 Z(NODE)=LLN
      IF (NHR.EQ.0) GO TO 4300
      ZFEAS=.FALSE.
      STOP
 4300 NAVL=NAVL+1
      KODE(NAVL)=NODE
      GO TO 4400
 4350 IF (Z(NODE).LT.UBD) GO TO 4400
      Z(NODE)=LLN
      NAVL=NAVL+1
      KODE(NAVL)=NODE
 4400 IF (NKTR.NE.0.OR.NKTR1.NE.0) GO TO 300
      GO TO 3250
 4450 JW=1
      NODE=NLBON
 4500 IF (K2(NODE,JW)) GO TO 4550
      JW=JW+1
      GO TO 4500
 4550 KKW=JW
      JW=JW+1
C
C     MWS
      IF(JW.GT.NW.AND.MWS.LE.4) GO TO 5000
      IF(JW.GT.NW) GO TO 5450
      GO TO (4600,4700,4800,4900,5050,5150,5250,5350),MWS
 4600 DO 4650 I=JW,NW
      IF (.NOT.K2(NODE,I)) GO TO 4650
      IF (MDELS(NODE,KKW).GE.MDELS(NODE,I)) GO TO 4650
      KKW=I
 4650 CONTINUE
      GO TO 5000
 4700 DO 4750 I=JW,NW
      IF (.NOT.K2(NODE,I)) GO TO 4750
      KKW=I
 4750 CONTINUE
      GO TO 5000
 4800 DO 4850 I=JW,NW
      IF (.NOT.K2(NODE,I)) GO TO 4850
      IF (MEGAS(NODE,KKW).GE.MEGAS(NODE,I)) GO TO 4850
      KKW=I
 4850 CONTINUE
      GO TO 5000
 4900 DO 4950 I=JW,NW
      IF (.NOT.K2(NODE,I)) GO TO 4950
      IF (Y(NODE,KKW).GE.Y(NODE,I)) GO TO 4950
      KKW=I
 4950 CONTINUE
 5000 NKTR=2
      GO TO 300
 5050 DO 5100 I=JW,NW
      IF (.NOT.K2(NODE,I)) GO TO 5100
      IF (MDELS(NODE,KKW).LE.MDELS(NODE,I)) GO TO 5100
      KKW=I
 5100 CONTINUE
```

```
      GO TO 5450
 5150 DO 5200 I=JW,NW
      IF (.NOT.K2(NODE,I)) GO TO 5200
      KKW=I
 5200 CONTINUE
      GO TO 5450
 5250 DO 5300 I=JW,NW
      IF (.NOT.K2(NODE,I)) GO TO 5300
      IF (MEGAS(NODE,KKW).LE.MEGAS(NODE,I)) GO TO 5300
      KKW=I
 5300 CONTINUE
      GO TO 5450
 5350 DO 5400 I=JW,NW
      IF (.NOT.K2(NODE,I)) GO TO 5400
      IF (Y(NODE,KKW).LE.Y(NODE,I)) GO TO 5400
      KKW=I
 5400 CONTINUE
 5450 NKTR1=2
      GO TO 300
C
 5500 UBD=Z(NODE)
 5550 CONTINUE
      NFINAL=1
      WRITE(3,5551)
 5551 FORMAT(1H1)
      WRITE(3,157)ITER
 157  FORMAT(25X, ' TOTAL NUMBER OF ITERATIONS WAS ',I11)
      WRITE(3,158)NODE
 158  FORMAT(25X, ' TOTAL NUMBER OF DISTINCT NODES IS ',I8)
      NODE=NUBDN
      GO TO 1100
 5555 CONTINUE
      WRITE(3)
      WRITE(3,159)UBD
 159  FORMAT(25X, ' EXACT OR HEURISTIC SOLN =',I10)
      WRITE(3,160)
 160  FORMAT(25X, 'OPEN AMF"S ARE ')
      DO 7870 I=1,NW
      IF(Y(NUBDN,I).NE.0.0)WRITE(3,161) I
 161  FORMAT(44X,I5)
 7870 CONTINUE
 7864 FORMAT(/,25X,10I10)
      WRITE(3,162)
      WRITE(3,164)
 164  FORMAT(30X,'PS  AMF  V COST',/)
      DO 5700 J=1,NC
      ISTAR=IDEL(NUBDN,J)
      WRITE(3,7864)J,ISTAR,IVC(ISTAR,J)
 5700 CONTINUE
      GO TO 200
 5800 CONTINUE
      STOP
      END
```

QUESTIONNAIRE FOR DETERMINING

CRITERIA FOR FDD

PART I - FAULT DETECTION AND DISPATCH (FDD) CRITERIA

Note: Criteria are the characteristics that will be used to evaluate the performance of alternative candidate systems.

Each criterion and its relative importance will be used in an analytical model to help select the optimal candidate system for the FDD.

The following characteristics are suggested as criteria for the FDD activities and equipment. Please indicate your approval/disapproval of each by circling the appropriate "YES" or "NO".

1. Availability — YES NO

   This relates to the operational availability of the MX fleet.

2. Comparative Costs — YES NO

   The cost of a given alternative candidate system relative to a standard cost.

3. Team Utilization — YES NO

   The level of activity for the maintenance teams measured as a fraction of their available time.

4. Vehicle Utilization — YES NO

   The average number of hours per month of vehicle usage.

5. Strategic Arms Limitation Verification (SAL VER) — YES NO

   The ability of a candidate system to support SAL VER.

6. Preservation of Location Uncertainty — YES NO

   The preservation of location uncertainty during maintenance and operations

If you feel that other criteria should be included please list and define them below:

7. ______________________ YES NO

Definition:

8. ______________________ YES NO

Definition:

9. ______________________ YES NO

Definition:

PART II

Please indicate below how you rate each criterion in importance with 10 being most important, 0 least important. Note that these will be used to estimate the relative importance of each criterion with respect to the others.

1. Availability

   0 1 2 3 4 5 6 7 8 9 10

2. Comparative Costs

   0 1 2 3 4 5 6 7 8 9 10

3. Team Utilization

   0 1 2 3 4 5 6 7 8 9 10

4. Vehicle Utilization

   0 1 2 3 4 5 6 7 8 9 10

5. Stragetic Arms Limitation Verification (SAL VER)

   0 1 2 3 4 5 6 7 8 9 10

6. Preservation of Location Uncertainty

   0 1 2 3 4 5 6 7 8 9 10

7. ______________________________

   0 1 2 3 4 5 6 7 8 9 10

8. ______________________________

   0 1 2 3 4 5 6 7 8 9 10

9. ______________________________

   0 1 2 3 4 5 6 7 8 9 10

AD-A078 805 HOUSTON UNIV TEX F/G 22/2
PRELIMINARY ACTIVITIES IN THE DEVELOPMENT OF MX MAINTENANCE CON--ETC(U)
SEP 79 B OSTROFSKY F49620-77-C-0116
UNCLASSIFIED AFOSR-TR-79-1279 NL

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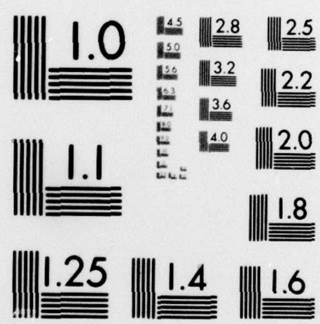

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

PARAMETERS y_k	x_1 PLU					x_2 AVAILABILITY						x_3 COST, COMPARATIVE						x_4 TEAM UTILIZATION						x_5 VEHICLE & EQUIP UTILIZATION						x_6 SALT VERIFICATION
	NO. OF PERSONNEL (Z_i)	NO. OF VEH./EQUIP./FAC. (Z_i)	TASK TIME (Z_i)	$x_1=f_1(y_k)$	FREG. OF ACTION (Z_i)	NO. OF PERSONNEL (Z_i)	NO. OF VEH./EQUIP./FAC. (Z_i)	TASK TIME (Z_i)	ALERT TIME (Z_i)	TRAVEL TIME (Z_i)	$x_2=f_2(y_k)$	NO. OF PERSONNEL (Z_i)	NO. OF VEH./EQUIP./FAC. (Z_i)	TASK TIME (Z_i)	TESTING, OPERAT. & SPARE COST	$x_3=f_3(y_k)$	TRAVEL TIME (Z_i)	NO. OF PERSONNEL (Z_i)	TASK TIME (Z_i)	TOTAL TIME AVAILABLE (TEAM)	FREG. OF ACTION (Z_i)	$x_4=f_4(y_k)$	TRAVEL TIME (Z_i)	NO. OF VEH./EQUIP./FAC. (Z_i)	TASK TIME (Z_i)	TOTAL TIME AVAILABLE (V/E)	FREG. OF ACTION (Z_i)	$x_5=f_5(y_k)$	TRAVEL TIME (Z_i)	$x_6=f_6(y_k)$
NUMBER OF PERSONNEL (Z_i)	✓					✓						✓						✓												
NUMBER OF VEH./EQUIP./FAC. (Z_i)		✓					✓						✓											✓						
TASK TIME (Z_i)			✓					✓						✓					✓						✓					
ALERT TIME (Z_i)									✓																	✓				
TRAVEL TIME (Z_i)										✓							✓						✓						✓	
TOTAL TIME AVAILABLE (TEAM) (Z_i)																				✓										
TOTAL TIME AVAILABLE (V.E.) (Z_i)																										✓				
TESTING, OPERATING, SPARE COST (Z_i)															✓															
FREG. OF ACTION (Z_i)					✓																✓						✓			
NUMBER OF AMF	✓	✓			✓	✓	✓					✓	✓					✓			✓						✓			
NUMBER OF SMSB'S	✓	✓			✓	✓	✓					✓	✓					✓		✓	✓			✓			✓			
NUMBER OF MULTIPLE SKILL TEAM	✓					✓						✓						✓		✓										✓
NUMBER OF INSPECTION TEAM	✓					✓						✓						✓		✓										
NUMBER OF AVE MOVING TEAM	✓					✓						✓						✓		✓										✓
NUMBER OF OSE R/R TEAM	✓					✓						✓						✓		✓										✓
NUMBER OF C^3/SECURITY REPAIR TEAM	✓					✓						✓						✓		✓										
SIZE OF MULTIPLE SKILL TEAM	✓					✓						✓						✓		✓										
SIZE OF INSPECTION TEAM	✓					✓						✓						✓		✓										
SIZE OF AVE MOVING TEAM	✓					✓						✓						✓		✓										
SIZE OF OSE MOVING TEAM	✓					✓						✓						✓		✓										
SIZE OF OSE R/R TEAM	✓					✓						✓						✓		✓										
SIZE OF C^3/SECURITY REPAIR TEAM	✓					✓						✓						✓		✓										
NUMBER OF AVE R/R TEAM	✓					✓						✓						✓		✓										
NUMBER OF HELICOPTERS		✓					✓						✓											✓		✓				
NUMBER OF VANS		✓					✓						✓											✓		✓				✓
NUMBER OF TRANSPORTERS		✓					✓						✓											✓		✓				✓
NUMBER OF PS					✓				✓												✓						✓			✓
NUMBER OF SITE VISITS / VAN / DAY		✓					✓						✓		✓									✓		✓				
NUMBER OF SITE VISITS / TRANSPORTER / DAY		✓					✓						✓		✓									✓		✓				
NUMBER OF MISSILES EMPLACED					✓				✓						✓						✓						✓			✓
DISTANCE BETWEEN PS										✓							✓						✓						✓	✓
AREA (TOTAL & USABLE)					✓						✓					✓					✓						✓			✓
TIME TO ENTER/EXIT SITE			✓					✓						✓					✓						✓					✓
TIME TO EMPLACE AVE.			✓					✓						✓					✓						✓					✓
TIME TO EMPLACE OSE			✓					✓						✓					✓						✓					✓
TIME TO INSPECT AVE			✓					✓						✓					✓						✓					
TIME TO INSPECT OSE.			✓					✓						✓					✓						✓					
TIME TO REPAIR AVE.			✓					✓						✓					✓						✓					
TIME TO REPAIR OSE.			✓					✓						✓					✓						✓					
TIME TO REPAIR RSE.			✓					✓						✓					✓						✓					
CAPABILITY TO OVER RIDE COMPUTER				✓																										✓
NUMBER OF LRU/AVE					✓				✓						✓						✓						✓			
NUMBER OF LRU/OSE					✓				✓						✓						✓						✓			
NUMBER OF LRU/RSE					✓				✓						✓						✓						✓			
PERSONNEL SUPPORTING COST																✓														
ROAD MATERIALS															✓															
SAFETY OF EQUIPMENT															✓	✓														
FAILURE RATE / LRU / AVE					✓				✓						✓						✓						✓			
FAILURE RATE / LRU / OSE					✓				✓						✓						✓						✓			
FAILURE RATE / LRU / RSE					✓				✓						✓						✓						✓			
FAILURE RATE / VAN		✓					✓		✓				✓											✓		✓				
FAILURE RATE / TRANSPORTER		✓					✓		✓				✓											✓		✓				
FAILURE RATE / HELICOPTER		✓					✓		✓				✓											✓		✓				
TOTAL NUMBER OF AVE FAILURE					✓				✓						✓						✓						✓			
TOTAL NUMBER OF AVE NO LAUNCH FAILURE					✓				✓						✓						✓						✓			
TOTAL NUMBER OF OSE FAILURE					✓				✓						✓						✓						✓			
TOTAL NUMBER OF OSE NO LAUNCH FAILURE					✓				✓						✓						✓						✓			
TOTAL NUMBER OF RSE FAILURE					✓				✓						✓						✓						✓			
TOTAL NUMBER OF VAN FAILURE		✓					✓						✓											✓		✓				
TOTAL NUMBER OF TRANSPORTER FAILURE		✓					✓						✓											✓		✓				
TOTAL NUMBER OF HELICOPTER FAILURE		✓					✓						✓											✓		✓				
SPEED OF VAN		✓					✓			✓					✓		✓						✓	✓		✓			✓	
SPEED OF TRANSPORTER		✓					✓			✓					✓		✓						✓	✓		✓			✓	
SPEED OF HELICOPTER		✓					✓			✓					✓		✓						✓	✓		✓			✓	
NUMBER RSE REPAIR TEAM	✓					✓						✓						✓		✓										
SIZE OF RSE REPAIR TEAM	✓					✓						✓						✓		✓										
SIZE OF AVE R/R TEAM	✓					✓						✓						✓												
SECURITY REACTION TIME				✓						✓							✓						✓						✓	
NUMBER HRS / DAY / MAN																✓				✓										
NUMBER DAYS / BASE PERIOD																✓				✓						✓				
NUMBER HRS/DAY/VAN																✓										✓				
NUMBER HRS/DAY/TRANSPORTER																✓										✓				
COST/VAN																✓														
COST/TRANSPORTER																✓														
COST/HELICOPTER																✓														
PERSONNEL COST/OSE R/R TEAM																✓														
PERSONNEL COST/AVE R/R TEAM																✓														
PERSONNEL COST/MULTIPLE SKILL TEAM																✓														
PERSONNEL COST/OSE MOVING TEAM																✓														
PERSONNEL COST/AVE MOVING TEAM																✓														
PERSONNEL COST/INSPECTION TEAM																✓														
PERSONNEL COST/C^3-SECURITY REPAIR TEAM																✓														
PERSONNEL COST/RSE REPAIR TEAM																✓														